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PHYSIOLOGICAL FACTORS RELATED TO EARLINESS IN VEGETABLE CROPS

by

© ROBERT JAMES EWING

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ABSTRACT

Five factors were investigated from 1976 to 1978 to determine whether they had any relationship to the time needed to mature various cultivars of a species.

Lycopersicon esculentum cultivars used throughout this study were: Rocket, Early Girl, Itabec, Ultra Girl, VFN 8, XP 271 and Redstone. *Brassica oleracea* var. *capitata* cultivars were: Golden Cross, Ventura, Jet Pak, Earlimart, Early Vienna, Red Head and Storage Green. *Beta vulgaris* cultivars were: Mono Germ, Burpee's Golden, Early Wonder, Cylindra, Detroit Dark Red, Green Top Bunching and Winter Keeper.

Respiration rates were measured by Warburg respirometry at 27°C. Rates in *Lycopersicon esculentum* varied from 5.8 to 25.8 mg O_2 uptake · gram dry wt^{-1} · $hour^{-1}$. In *Brassica oleracea* rates varied from 48.1 to 186.8 mg O_2 uptake · gram dry wt^{-1} · $hour^{-1}$. In *Beta Vulgaris* rates varied from 8.6 to 123.9 mg O_2 uptake · gram dry wt^{-1} · $hour^{-1}$. There was no relationship between respiration rates and days needed to reach maturity in the cultivars tested. A relationship with time of day was noted. Respiration rate was greatest in the morning, decreased toward noon, and increased in the afternoon.

Cultivars differed in peroxidase activity but no correlation with days needed to reach maturity was found.

Peroxidase activity was lower (0.0026 K/gram) in midseason cultivars and higher in earlier (0.0042 K/gram) and later (0.0057 K/gram) cultivars of *Lycopersicon esculentum*. Peroxidase activity in *Brassica oleracea* var. *capitata* varied from 0.0074 to 0.0221 K/gram. No pattern was found.

There was no significant difference in rates of net assimilation of CO_2 between cultivars differing in days needed to reach maturity. *Lycopersicon esculentum* cultivars assimilated CO_2 at 0.82 to 3.10 mg $CO_2 \cdot dm^{-2} \cdot hr^{-1}$. *Brassica oleracea* var. *capitata* assimilated CO_2 at 2.38 to 4.08 mg $CO_2 \cdot dm^{-2} \cdot hr^{-1}$. *Beta vulgaris* assimilated CO_2 at 0.29 to 8.03 mg $CO_2 \cdot dm^{-2} \cdot hr^{-1}$. Measurements were made at 24°C with light levels ranging between 0.023 to 0.182 cal $\cdot cm^{-2} \cdot min^{-1}$. A comparison of assimilation in terms of leaf area and leaf weight indicated that leaf area may be the most discriminating method.

Leaf area of *Lycopersicon esculentum* was measured at three and seven weeks from germination. Both times leaf area was greater in midseason cultivars (17.90 cm^2 at three weeks and 905.37 cm^2 at seven weeks) and less in earlier (9.14 cm^2 at three weeks and 485 cm^2 at seven weeks) and later (10.56 cm^2 at three weeks and 479.32 cm^2 at seven weeks) cultivars. A theory was advanced in attempt to explain this relationship. Similar relationships existed with *Brassica oleracea* var. *capitata* and *Beta vulgaris*.

Shoot:root ratios in certain stages of the plant's life had a similar relationship with days needed to reach

maturity as did leaf area.

At seven weeks from germination of *Lycopersicon esculentum* the cultivars differed significantly and varied from 3.3253:1 to 5.0172:1. *Brassica oleracea* var. *capitata* cultivars varied significantly at seven weeks from germination from a low of 3.8883:1 to a high of 5.1849:1. *Beta vulgaris* cultivars differed significantly at five weeks from germination and varied from 1.7760:1 to 2.7519:1. The leaf area theory was expanded to include the root factor. Shoot:root ratios changed as the plants matured.

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This work is dedicated to both my wife and my parents.

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INTRODUCTION

Why do cultivars of the same species differ so greatly in the time they require to mature? The Subarctic Cherry tomato matures more than forty days earlier than the Redstone tomato (Hogue and Andrew, 1976). Considering the short growing season on the Canadian prairies this degree of difference could determine success or failure for the grower. Since earlier maturing cultivars do not grow as long as later ones their yield is generally less, but at least they can mature in short season areas. Without short season cultivars people in these areas are forced to import all or more tomatoes than would be necessary if they were developed and used regionally.

The problem for the plant breeder is development of earlier cultivars. Presently the only way to do this is by the time, energy and space consuming selection of early cultivars which have grown on to maturity. An alternative would be identification of plants which show promise by some easily performed test done early in their life cycle.

At the same time more fundamental studies are necessary and an understanding of what is meant by maturity is the starting point. Badani (1974) based his studies of earliness upon commercial maturity, not physiological maturity. Commercial maturity is the point where the crop is ready for harvest. That point for the crops used in this study was: in tomato (*Lycopersicon esculentum* L.) when the pink coloration

on the distal end was starting to show; in cabbage (*Brassica oleracea* var. *capitata* L.) when the head reached optimum size and firmness; and in red beet (*Beta vulgaris*) when the root reached optimum size without being fibrous, bitter, or split. The days to maturity were calculated from the germination date to this imposed stage of maturity.

Physiological maturity is reached when a plant enters its reproductive stage, usually indicated by flowering. Measurement of development and growth of leaves is one useful scale of physiological time according to Maksymowych (1973) and may be correlated with the biochemical changes occuring in the plant. If this definition of physiological maturity is accepted then it would follow that a species like tomato would be physiologically mature when it is commercially mature but red beet or cabbage would not be because they have not flowered. For this reason physiological studies such as those done by Pandita (1966), Casement (1975), and Badani (1974) that use the same physiological determinant for various species should not be rejected if correlation does not occur in all cases. Determinants that correlate physiological processes with commercial maturity need to be sought for each species.

The current study attempted to find suitable physiological correlatives for each of the three commercial crops mentioned earlier. Respiration, peroxidase activity, net assimilation, shoot:root ratios, and leaf area were the factors considered.

LITERATURE REVIEW

I. The Role of Respiration of Leaf Tissue in Relationship to Earliness

A) Respiration, a basic plant function

Respiration is an energy producing process in which fuel type molecules such as glucose produced from photosynthesis are oxidized to produce energy molecules like ATP. Acetyl-CoA formed from glucose enters the tricarboxylic acid cycle releasing CO_2, GTP and H atoms. The H atoms then enter the electron transport chain producing the main energy carriers, ATP, and water. The process consumes oxygen producing CO_2, H_2O and ATP.

$$\text{Glucose} + 6O_2 + 36\text{Pi} + 36\ \text{ADP} \rightarrow 6CO_2 + 36\ \text{ATP} + 42\ H_2O$$

(Lehninger, 1975)

Many intermediates of the TCA cycle are vital to other metabolic processes. Braunstein (1947) indicates their importance in amino acid metabolism; Burris (1953) and Thimann and Bonner (1950) in the interrelationship of fat, carbohydrate, and protein metabolism. Wherever energy needs are high, mitochondria, containing respiratory enzymes are concentrated. Sites of biosynthesis such as in shoot apices and active transport sites in roots are examples. A number of respiratory intermediates form the carbon skeleton for

amino acids and eventually protein building blocks. Nucleic acid synthesis begins in the related pentose shunt. Also the respiratory system supplies precursors for polysaccharides.

B) Mitochondrial respiration in relation to plant yield

Energy is essential to the growth of any organism. From the time of seed germination (Cameron, 1965) active energy production is carried out and the degree of activity has a definite influence on the rate of germination. Sage and Hobson (1973) state that the "efficiency with which a plant can generate energy for cellular work may be regarded as just one component of yield, but presumably a very basic one". They made a 1:1 mixture of parental mitochondria, examined its energy efficiency in relation to the parental efficiency and predicted yield of the F_1 hybrid. They found a correlation between predicted and actual yield but only when the seed density was low. At higher densities the correlation did not hold because expression of this component was depressed. Sarkissian and Srivastava (1967) (1969) in maize and wheat, and McDaniel (1972) in barley found correlations between mitochondrial activity and F_1 seedling yield. Ellis et. al. (1973) doing similar studies with barley were unable to get similar mitochondrial complementation despite careful attention to published procedures. They conclude that more procedural details are necessary.

C) Respiration and plant growth

A faster rate of respiration has been demonstrated in tall pea cultivar internode segments than in dwarf cultivars (Israelstam and Fukumoto, 1974). This was done in dark grown plants but similar results were obtained in light grown ones (Israelstam and Fukumoto, 1977). Cell fractions were identical for both tall and dwarf cultivars in the discontinuous sucrose density gradient centrifugation. Three substrates, succinate, NADH, and malate, were used in the polargraph recordings. With all three substrates the R.C. index and P:O ratio were higher in the tall cultivar. They speculated that the greater activity of the tall plant mitochondria was due to lack of inhibition by oxaloacetate and that mitochondrial activity is is related to gibberellic acid hormone activity. Greater concentrations of gibberellin were found in the tall cultivars. They suggested that a lack of it causes poor phosphorylation coupling to oxidation resulting in dwarfing.

Doney et. al. (1973) found a correlation between more efficient mitochondria, in terms of adenosine diphosphate to oxygen ratio, and faster growth rates. Efficiency was positively correlated with root fresh weight and total weight.

D) Respiratory changes and photoperiodic induction

In many plants photoperiod is responsible for inducing flowering. Elliott and Leopold (1952) investigated associated respiratory changes. In short-day plants subjected to a short day followed by a long night, a decrease in respiration

was observed. However if the short day/long night photoperiods were continued over two or three days increases of up to 18% were observed in cockleburs and 45% in Biloxi soybean. Positive correlation between respiration rate and number of flower primordia induced was found.

In long-day plants one inducing day increased respiration, whereas two or three days reduced it as much as 21% below vegetative control levels. Respiration rates of indeterminate plants depended only on the total light received.

E) Respiration and earliness

Respiration is a basic process similar in all plants. Rates of respiration though, may vary considerably as does any biological function. Enzymes involved may vary in efficiency due to their proximity to substrate sources and other enzymes in the chain. Minute differences in structure could alter enzyme active sites, changing efficiency. These things are under hereditary control. Since respiration controls so many things is it related to earliness? The availability or shortage of substrates for protein synthesis, polysaccharides, and other polymers may have an effect on how a plant can grow and mature. An abundant supply of energy, ATP, may enable maturing reactions to proceed more rapidly.

Conversely, limiting factors such as insufficient nitrogen or water may result in hastening of the maturation process (Blackman, 1905). Physiological limitations may

have similar effects. A less efficient respiratory system could cause many limitations in energy and precursors for metabolism.

Yield is usually greater when the plant has a longer period of growth. Conversely early maturity usually means a smaller yield. If respiration was less efficient then metabolic precursors and energy may become limiting, resulting in a smaller yield and earlier maturity.

Respiration's complex relationship with photoperiod suggests the vegetative phase activity. If a long day plant has lower respiration after flower initiation then it must be higher in the vegetative phase. The short day plants would have lower respiration in the vegetative phase than after flower initiation.

Temperature may play an important role in earliness. Early maturing cutlivars may be able to acclimate to the lower temperatures that occur in the spring. There may be a similarity between early cultivars and arctic species which often have higher respiration than non-arctic species at low temperatures.

Respiration is a vital function affecting every phase of growth. It is not a fixed reaction but changes according to internal and external factors.

II. Relationship of Peroxidase and Earliness

A) Role of peroxidase in plant metabolism

Oxidation of many organic compounds is performed by peroxidase using hydrogen peroxide. Examples are amines, phenols and leuco-dyes. Peroxidase is highly specific for peroxide, yet peroxidase-hydroperoxide complex specificity for organic compounds is low (Luck, 1963).

$$AH_2 + H_2O_2 \xrightarrow{\text{peroxidase}} 2H_2O + A$$

Hydrogen peroxide is formed in a number of ways. Amino acid oxidases react with oxygen resulting in hydrogen peroxide.

$$\text{Enzyme} - FADH_2 + O_2 \longrightarrow E - FAD + H_2O_2$$ (Lehninger, 1975)

Glycolic acid oxidase produces hydrogen peroxide in converting glycolate to glyoxylate:

$$\text{Glycolate} + O_2 \xrightarrow[\text{oxidase}]{\text{glycolic acid}} \text{glyoxylate} + H_2O_2$$

(Bidwell, 1974).

This reaction is part of photorespiration and occurs in the peroxisomes.

Peroxidase can oxidize NADH or NADPH and thereby put a control on cellular metabolism. Kaur-Sawhney et. al. (1972) have noted inhibition of peroxidase formation when IAA is applied to pith tissue. They suggest that this could be a

control mechanism. Kinetin has the opposite effect of stimulating peroxidase formation.

In experiments with four nearly isogenic sorghum cultivars it was found that peroxidase activity was higher in shoots of shorter cultivars than in tall cultivars. This was also true in seeds; shorter cultivar seeds having more activity than tall cultivar seeds. Also seed viability positively correlated with peroxidase activity. Roots have more peroxidase activity than shoots (Liang, et. al., 1973).

Peroxidase is connected with injury and disease. Birecka and Miller (1974) found cell wall fractions of carrot roots contribute 95% of peroxidase activity. The activity increased when the tissue was injured. Peroxidase activity was greatest in peach seedlings, medium in apricot and lowest in plum seedlings. Zonev et. al. (1973) found that lower enzyme activity was related to higher plum pox virus susceptibility.

B) Relationship of peroxidase and earliness

A number of Russian researchers have studied the relationship of peroxidase and earliness. In apple the level of peroxidase activity was found to be higher in early than in midseason and late cultivars. Wet weather decreased peroxidase activity and delayed vegetative growth (Egle and Ekovich, 1972). In tomato, Bontar et. al. (1974) found peroxidase activity in the leaves of hybrids was intermediate between that of the parents except in the budding and flowering stages.

None of these studies have predictive value having been done on older plants, however indications are obvious.

One study by Daskaloff, et. al. (1972) indicated that it would be possible to predict earliness on the basis of peroxidase activity. Several tomato cultivars and their F_1 crosses were examined. Early cultivars had higher peroxidase activity in the seedlings than late ones. The F_1 cross seedlings were intermediate. They felt these results were not totally conclusive and more proof was needed. If it does prove true then it would be a valuable predictive tool for tomatoes. Tomatoes and other crops were further examined in relation to peroxidase in the present study.

III. Role of Net Assimilation in Relationship to Earliness

A) Role of assimilation in the plant

Photosynthesis and respiration are the two components of net assimilation. Photosynthesis is the utilization of light energy to synthesize energy storing compounds by the assimilation of CO_2. Respiration is the utilization of this chemical energy by breaking down carbon compounds and releasing CO_2. Net assimilation is the difference between the amount of CO_2 taken up and the amount released.

Assimilation of CO_2 is the mechanism by which carbon is incorporated into the plant in the form of organic carbon compounds. This occurs in two phases. The light reaction, which requires light, is the absorption of light energy by certain pigments and the conversion of it into chemical energy, ATP, and the reducing potential, NADPH. Hydrogen is removed from water, leaving oxygen. In the dark phase the energy from ATP and NADPH is used to reduce CO_2 to glucose. Overall reactions are:

$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$ (e.g. Lehninger, 1975)

B) Factors influencing net assimilation

Assimilation is influenced through either the light or dark reactions, and the interactions of these processes are complex.

Light is the most important. It can vary in intensity and duration. Apart from photoperiodic effects, duration is relatively simple. The longer light is available, the more assimilation can occur.

At lower light intensities rates of photosynthesis increase linearly with increasing intensity (Talling, 1961). As intensity increases a maximum rate is reached and maintained. This is light saturation or absolute capacity of the plant material and can be used to compare plants of different types. Bohning and Burnside (1956) differentiate between sun and shade plants. Sun plants were light saturated between 0.045 to 0.057 $cal \cdot cm^{-2} \cdot min^{-1}$, whereas shade plants were light saturated between 0.011 to 0.023 $cal \cdot cm^{-2} \cdot min^{-1}$. Compensation points for sun plants were 0.0023 to 0.0034 $cal \cdot cm^{-2} \cdot min^{-1}$, and for shade plants 0.0011 $cal \cdot cm^{-2} \cdot min^{-1}$. Survival for plants means photosynthesis exceeding respiration. Plants with high saturation regions may be better able to use all the light available which would be an advantage. A low compensation point is an asset in dark conditions in that it can still grow.

Wilson and Cooper (1969) state that net assimilation rate increases as light intensity increases. Light conversion efficiency is two to three times higher in low light or light limiting conditions.

Taylor and Rowley (1971) examined the effect of cool temperatures on photosynthesis. Upon the introduction of

chilling temperatures the photosynthetic rates of all species of C_3 and C_4 plants dropped but to different extents. Initial reduction was caused by direct effect on the leaf and by reduced water uptake by the roots. They also found a far greater reduction in photosynthesis in stress-intolerant species compared to semitolerant species when the temperatures were lowered at the commencement of the photoperiod rather than at mid-photoperiod.

Optimum temperature for photosynthesis in cucumber increases with increasing light intensity (Klueter, et. al., 1973). The optimum increased by 4°C for each additional 0.023 $cal \cdot cm^{-2} \cdot min^{-1}$ up to 0.136 $cal \cdot cm^{-2} \cdot min^{-1}$ at which point it was 36°C. At 0.182 $cal \cdot cm^{-2} \cdot min^{-1}$ the optimum was 40°C. Temperatures below optimum reduced CO_2 uptake more than higher temperatures before cooling. This, they believe, was caused by enzyme activation or change in stomatal activity. Above 44°C activity decreased and above 50°C damage occurred. Alternatively depressions in photosynthetic rates have been recorded at high temperatures especially in the late afternoon (Talling, 1961). It is suggested that this depression is related to a rise in respiration rate. Since temperature controls both photosynthsis and respiration, net assimilation rate is complicated.

Since CO_2 is the essence of assimilation and photosynthesis, its concentration will be important. When the normal CO_2 concentration of 0.03% is increased to 0.09%

yield increases may result. CO_2 levels vary with altitude, with diurnal photosynthesis and with air movement. Under normal light and temperature conditions CO_2 is the limiting factor.

Neales et. al. (1971) found a positive correlation between net photosynthetic rates and the activity of the enzyme ribulose -1,5- diphosphate carboxylase. They also found a positive correlation between net photosynthetic rates and leaf stomatal resistance.

Keerberg et. al. (1971) suggest the activity of ribulose -1,5- diphosphate carboxylase (part of the Calvin cycle), is influenced by light spectral composition. Also, they found red increased CO_2 assimilation into glycolic acid and glycine.

Hesketh (1963) after examining photosynthetic rates among different species concluded that the critical difference lies in mesophyll diffusion and the kinetics of the dark reactions.

After long exposure to light, assimilation may decrease. Upmeyer and Koller (1973) suggest that when a high starch level is reached, further starch synthesis is impaired, leading to an increase in soluble carbohydrate level and a reduction in net photosynthesis rate.

C) Net assimilation and earliness

It is known that high rates of photosynthesis are achieved in unfavourable habitats with short growing seasons. Greater variation occurs in species of continental climates than in moderate climate species. One example is *Aster*

tripolium. Its cultivars are known to differ in photosynthetic response (Talling, 1961).

Watson (1947) studied differences in net assimilation rates between species and varieties. Wheat was less than barley although wheat showed some variability depending upon the year. Sugar beet was twice that of wheat and also exceeded barley. Sugar beet was slightly higher than mangold. Potatoes had greater rates than barley or wheat. Between species he concluded that there are definite differences, especially between dicotyledons and monocotyledons; the dicots being greater.

Fewer differences were noted between varieties. There was no significant difference between wheat varieties. One sugar beet variety was different than the other two. Potato varieties showed a small variation in assimilation rate.

Badani (1974) has done some experimentation with vegetative earliness. His findings indicate changes in photosynthesis with age. The late maturing cultivars were more efficient early in development with net assimilation decreasing with age. The earliest cultivars showed an increase in net assimilation with age. Net assimilation rates increased proportionately with light intensity until the saturation point was reached. Effects of temperature were variable, possibly dependant on light intensity.

IV. Leaf Area and its Relationship to Earliness

A) Factors controlling leaf area

Gregory (1928) has studied the subject. His conclusions follow. Relative leaf growth-rate is independent of assimilation. At suboptimal temperatures, temperature affects apical bud development controlling rate of foliage leaf unfolding. However, relative leaf growth rate is temperature independent, but controlled by light intensity. A smaller leaf area results if either intensity or duration of light is reduced.

At temperatures above optimum, Gregory (1928) claims a time factor is in operation. At these high temperatures, materials are redistributed with more growth being made by the stem. Relative leaf growth rate is reduced because of a decrease in cell division in the leaf primodia resulting in fewer cells for expansion.

A second time factor is in operation. In low light conditions relative leaf growth-rate decreases with time. Increasing light intensity reverses the effect. A shoot-root interaction is indicated. If assimilation is low then the supply of carbohydrate to the root is decreased. In time this would result in the root supplying less nitrogen to the shoot which is necessary for leaf growth and expansion.

Mitchell et. al. (1975) found shaking plants or other mechanical stress decreases the number of leaves developing.

This could be of importance for tall varieties which are more exposed to the wind.

B) Leaf area and earliness

Grass and maize species expose a greater leaf area to sunlight above the compensation point than do dicotyledonous species (Brougham, 1960). Maximum growth occurs when there is sufficient leaf to intercept 95% of the incident light at local noon. The Leaf Area Index indicates the amount of leaf per unit of land and is known to vary greatly between species. The differences are due to growth habit, orientation, shape of leaves, light transmission through leaves and amount of chlorophyll per unit area. It is suggested that chlorophyll is more efficient in species with horizontal or flagged leaves, or that more dry matter is produced underground in erect leaf species.

Others have noted similar relationships. El-Sharkawy et. al. (1965) noted increased dry matter production in cotton when the rate of leaf area development increased.

Phyllotaxis has also been related to yield. Counter-clockwise phyllotaxis produced more fruit than clockwise in experiments on tomato and pepper (Bible, 1976).

Further studies on cotton (Muramoto et. al., 1965) have associated early development of leaf area with early flowering. Early development of photosynthetic area can extend the effective growing season. The hybrids had a

full set of leaves one week before their parents. This does not necessarily increase the vegetation but allows the plant to develop and flower sooner and longer resulting in increased yields of cotton.

Spatial arrangement of leaves was indicated above to have importance in yield. The effects are probably due to self shading. Imanishi and Hiura (1972) have found a negative correlation between the degree of leaf rolling and earliness in tomatoes. Possibly, the self shading from rolling has slowed growth delaying early development. The number of leaves among the eight cultivars did not differ, only the degree of rolling. Since rolling would decrease effective leaf area this study would correspond to Muramoto et. al. (1965). Leaf rolling is suspected of being genetically controlled.

Watson (1947) has examined leaf area and leaf number in three crops: wheat, sugar beet and potatoes. The measurements were taken at close to their maximum value. In all cases there was little difference in leaf area per plant between varieties. However leaf number differed considerably and consequently the mean area per leaf differed. Whether this difference in leaf area would correlate with earliness was an object of the present experiments.

Tan et. al. (1978b) noted one advantage of early large leaf area; the plant would have a competitive advantage against weeds.

V. Shoot:Root Ratio in Relationship to Earliness

A) Shoot and root relationships

There is a close relationship between shoot growth and root growth. The leaf surface through photosynthesis supplies carbohydrates which are a vital factor in root growth. Reciprocally roots take up soil nitrogen and supply it to the shoots resulting in leaf growth and expansion. If assimilation decreased there would be less storage carbohydrate available for root growth. Decreased root growth would limit available nitrogen and cause a decrease in shoot growth (Gregory, 1928).

Increasing the supply of nitrate in the nutrient solution leads to an increase in the ratio of top growth to root growth. Turner (1922) indicated that nitrate had little direct effect on root growth but the presence of carbohydrates did. When nitrates are increased shoot growth also increases and this growth uses more of the available carbohydrates leaving little for the roots. This results in a change in relative growth of shoot and roots.

Any condition limiting assimilation such as shade would cause a greater proportion of the available carbohydrate to be used in the shoots. This would mean less is available for the roots. Pruning similarly limits root more than shoot growth. Pruning decreases carbohydrate producing area but increases shoot vigor. This again increases the proportion

of carbohydrates used in the shoots and limits availability to the roots. Fordham (1972) noted that pruning *Camellia sinensis* stopped root growth for three months.

Fordham (1972) further noted that rapid shoot growth due to pruning or good growing conditions slowed root growth. Following the shoot growth period root production increased. This is again due to competition for carbohydrates. Once the shoots have slowed growth then there are abundant assimilates for the roots.

Roberts and Struckmeyer (1946) noted a number of shoot-root relations. Long day plants in long photoperiods have higher shoot:root ratios than in short photoperiods. Short day plants have higher shoot:root ratios in short days. This may be related to respiration as short photoperiods for short day plants and long photoperiods for long day plants corresponded to increased respiration (see pages 5 and 6).

They also noted temperature effects. It is indicated that some cool season crops have larger shoot:root ratios in warm conditions and some warm season crops had the larger ratio in cool conditions. This was not consistent but seemed to be related to flowering. As a plant begins to flower, shoot:root ratios increase.

Harris (1914) in moisture studies found increased root growth in drier soil. Even in germinating seed the shoot:root ratio was smaller in drier soil. Moisture had its greatest influence in the early stages of growth. He also

noted young plants have a lower shoot:root ratio than older ones. This may indicate a relationship with earliness.

B) Shoot:root ratio and earliness

Early cultivars of cabbage have less leaf area, less root area, and less dry weight than later cultivars. This is consistent with the fact that early maturing plants have less time to grow. In addition late varieties were found to have a higher shoot:root ratio (Tarakanov et. al., 1976). If early cultivars have this larger root then the plant would be more efficient in taking up nutrients and this abundance could allow the plant to develop faster. Since nutritional elements do not move rapidly in the soil, the large root area could result in localized limitation of phosphorus, for example, which may help bring on maturity by restricting normal root development (Badani, 1974).

Badani (1974) has done experiments on earliness with three cultivars in each of three species. His results suggest a relationship with predictive value between early shoot:root ratios and the time to maturation. This was especially true with tomatoes, less so with cabbage and lettuce. The experiments reported here were intended to expand the knowledge by using more cultivars.

GENERAL EXPERIMENTAL PROCEDURE

Procedures common to all parts of the thesis will be given here. Any exceptions will be noted under the specific procedures for that part.

A) Cultivars used

Three common vegetable crop species were examined. Tomato (*Lycopersicon esculentum* L.), is grown for its fruit and is judged mature when pink coloration starts to show on the distal end. Cabbage (*Brassica oleracea* var. *capitata* L.) is grown for the vegetative storage organ or head and is considered mature when optimum size and firmness of the head is reached. Red Beet (*Beta vulgaris* L.), grown for its storage root is considered mature when the root has reached optimum size without being fibrous, bitter or split.

Seven cultivars were chosen within each species. Previous experiments have used fewer, but it would make any correlation more meaningful if more are used. All cultivars have been tested over a number of seasons at the University of Alberta Parkland Farm and other experimental farms in western Canada (see Table 1). The information in Table 1 comes from the 1976 Vegetable Cultivar Trials (Hogue and Andrew, 1976). Days to maturity will vary from season to season, but the relative order is fairly consistent. Some cultivars are only two or three days apart and under some

Table 1a. Tomato cultivars used throughout this study

Cultivar	Days to Maturity From Field Set	Source
Rocket	64	Stokes Seeds, Ontario
Early Girl	67	Ball-Superior, Ontario
Itabec	74	Quebec Ag. Department
Ultra Girl	77	Stokes Seeds, Ontario
VFN 8	84	Asgrow, Michigan
XP 271	92	Asgrow, Michigan
Redstone	98	Asgrow, Michigan

Table 1b. Cabbage cultivars used throughout this study

Cultivar	Days to Maturity From Seed	Source
Golden Cross	78	Takii Seeds, Japan
Ventura	82	Keystone Seed Company, California
Jet Pak	85	Northrup, King and Co., Minnesota
Earlimart	92	Keystone Seed Company, California
Early Vienna	98	Keystone Seed Company, California
Red Head	106	Stokes Seeds, Ontario
Storage Green	130	Stokes Seeds, Ontario

Table 1c. Red Beet cultivars used throughout this study

Cultivar	Days to Maturity From Seed	Source
Mono Germ	45	Stokes Seeds, Ontario
Burpee's Golden	50	Stokes Seeds, Ontario
Early Wonder	55	Stokes Seeds, Ontario
Cylindra (Formanova)	58	Stokes Seeds, Ontario
Detroit Dark Red	60	Stokes Seeds, Ontario
Green Top Bunching	65	Stokes Seeds, Ontario
Winter Keeper	78	Stokes Seeds, Ontario

conditions may not be significant. The value will be in their relative order between earlier and later cultivars.

All plants were grown in either greenhouses or growth chambers to have more control of growth conditions.

Except where noted the following artificial soil media was used.

Table 2. Cornell Peat-Lite Mix

Peat moss	1 cu. ft.
Vermiculite	1 cu. ft.
Ground limestone	141.90 gm.
Superphosphate (0-20-0)	56.76 gm.
Potassium nitrate (12-0-44)	28.38 gm.
Fritted trace elements (7.00% iron 3.20% copper 3.20% zinc 2.52% manganese 0.68% boron 0.13 molybdenum)	3.55 gm.

This allowed for more exact control of fertility and texture and eliminated weed and soil borne disease problems.

PART ONE

POSSIBLE RELATIONSHIP BETWEEN LEAF RESPIRATION AND DAYS TO MATURITY

A) Materials and Methods

These experiments were conducted over two years. The work with cabbage was done in the summer of 1977 and tomato and beet in the summer of 1978.

Seventy seeds of each cutlivar were sown in flats filled with Cornell mix using a row spacing of 6.5 cm. The seedlings were germinated in the greenhouse with 16°C night temperatures and natural light. One week after germination seedlings were pricked out into six inch pots for tomato and cabbage and five inch for beet. The seedlings were selected on the basis of uniformity. The pots were placed randomly on the greenhouse compartment bench to minimize microclimate variations.

Fertilization was done every two weeks with 20-20-20 at 1.5 gm./liter; applied 290 ml. per six inch pot and 215 ml. per five inch pot.

Harvesting Samples

The harvest began four weeks after germination. Due to a limited number of Warburg respirometers, cultivars had to be grouped. The first run included for example, cultivars

A, B, and C; the second run, cultivars A, D, and E; and the third run, cultivars A, F and G. There were three replications of each cultivar. Other harvests were at the fifth and sixth week. The measurements were done within a 24 hour period. The runs were scheduled as equipment was available. Where possible the first run was at 9 a.m., the second at 12 noon, and the third at 3 p.m. In two cases this was not possible. In cabbage week four, and beet week six, the first run was at 3 p.m., the second at 9 a.m. the following morning, and the third at 12 noon. Cultivar A was measured each run to allow for comparisons between runs, i.e. with B and C, with D and E, and with F and G. The noon and 3 p.m. measurements were adjusted to allow comparison with the 9 a.m. measurment. The third leaf from the base of the plant was taken for measurement.

Measurements

The leaf samples were taken to a dark room to stop photosynthesis. Eleven Warburg flasks and manometers were prepared. A #2 filter paper moistened with 1/10 ml of distilled water and cut to fit, was placed in the bottom of each flask. A roll of filter paper was placed in the center well and moistened with 2/10 ml of 20% KOH. The top of the well was greased to prevent creeping. Leaf discs were cut to fit the bottom of the flask and placed in with the lower surface upwards. Two flasks were used as thermobarometers and contained everything but the

leaf sample and were used to measure volume changes other than those caused by oxygen uptake by the leaf. The flasks were sealed to the manometers and shaken in a water bath at 27°C in the dark room. One half hour was allowed for equilibration. Readings were taken every half hour for two hours.

After the readings were taken the leaf tissue was removed, placed in a 75°C constant temperature oven for 15 hours. The dry weight was measured.

This apparatus measures respiration in terms of millilitres of uptake of O_2 per gram of leaf tissue. These measurements were then converted to milligrams uptake of O_2 per gram of leaf tissue. Since respiration also evolves CO_2 it is absorbed immediately by the KOH.

The same procedure was used for all three species and was repeated at weeks four, five and six using new plants of the same cultivar.

B) Results

1. Tomato

In the first group of three cultivars no significant differences were found among them in respect to rates of respiration. The rate of respiration increased slightly between the fourth and fifth week and decreased sharply in the sixth week. The results are summarized in Table 3.

A correlation coefficient of 0.91 was found for the

fifth week from maturity for the second group of three cultivars. Also for this week the analysis of variance indicated a significant difference at the 1% level. Weeks four and six had no significant difference between the same cultivars. There was a sharp decrease in respiration rate between weeks four and five with only a marginal increase in week six. The results are summarized in Table 4.

In the third group of cultivars, which had the greatest spread in days to maturity, no significant difference in respiration rates were found. The respiration rate decreased as the plants aged. The results are summarized in Table 5.

As Table 6 indicates there was a very significant relationship between rate of respiration and time of day. Respiration was highest in the morning, lowest around noon and increased again in the late afternoon.

The cultivar Rocket was common to the three groups and this allowed the second and third group of cultivars to be adjusted to allow a comparison with the first group of cultivars. There was no significant difference in respiration among cultivars. The results are summarized in Table 7.

2. Cabbage

A significant difference at the 5% level was found for the first group of three cultivars at week four. The correlation coefficient of -0.52 was not significant. There was no significant difference among cultivars at weeks five and six. In this trial respiration rates appeared to increase with age. The results are summarized in Table 8.

In the second group of three cultivars no significant difference was found among them. In contrast to the first group respiration rates decreased with age. The results are presented in Table 9.

Again no significant difference in respiration rates was found in the third group with the widest spread in days to maturity. The results are presented in Table 10.

Golden Cross was the common cultivar among the three groups and this allowed the noon and 3 p.m. measurements to be adjusted to allow comparison with the 9 a.m. measurement. The results are summarized in Table 12. There was no significant difference in respiration among cultivars.

The difference between times of day was significant at the 1% level for all weeks examined. The rate was highest in the morning, usually lower at noon (except week four), with little change in the late afternoon (see Table 11).

3. Beet

In the first group of three cultivars, no significant differences were found with respect to rates of respiration. Respiration rates changed with age and increased from week four to week five but decreased by week six. The results are summarized in Table 13.

No significant differences were found among the three cultivars in the second group at any of the weeks measured. The cultivars showed few differences between week four and week five but increased in week six. The results are summarized in Table 14.

The analysis of variance of the third group of three cultivars showed a significant difference at only the fourth week. A correlation coefficient of -0.62 was calculated but it is not a significant correlation. The respiration rate increased slightly between the fourth and fifth weeks, then dropped in the sixth. The results are presented in Table 15.

The cultivar Monogerm was common to all three groups and this allowed the noon and 3 p.m. measurements to be adjusted to allow comparison with the 9 a.m. measurement. The results are summarized in Table 17. There was no significant difference in respiration among cultivars.

Table 10 shows a comparison of respiration rate with time of day. There was a significant difference in respiration rates. It was high in the morning, decreased by noon, and

decreased again in the late afternoon of week four.

Table 3. Days to maturity and average respiration at 27°C of three replications of the first group of three cultivars of *Lycopersicon esculentum*, four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
		Week 4	Week 5	Week 6
Rocket	64	19.8	24.3	9.2
Early Girl	67	19.8	21.7	8.4
Itabec	74	20.5	23.5	9.0
Correlation: average respiration and days to maturity		N.S.	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicates no significant difference between cultivars.

Table 4. Days to maturity and average respiration at 27°C of three replications of the second group of three cultivars of *Lycopersicon esculentum*, four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$) Week 4	Week 5**	Week 6
Rocket	64	10.8	6.1	6.5
Ultra Girl	77	11.4	6.2	6.5
VFN 8	84	11.0	6.5	6.5
Correlation: average respiration and days to maturity		N.S.	0.91	N.S.

N.S. Analysis of variance on replicated trials indicates no significant difference between cultivars.

** Significant difference at 1% level from analysis of variance.

Table 5. Days to maturity and average respiration at 27°C of three replications of the third group of three cultivars of *Lycopersicon esculentum*, four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
		Week 4	Week 5	Week 6
Rocket	64	20.9	14.4	9.6
XP 271	92	20.8	13.8	10.0
Redstone	98	22.0	14,0	10.3
Correlation: average respiration and days to maturity		N.S.	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicates no significant difference between cultivars.

Table 6. Relationship between the time of day respiration measurement started and the average respiration at 27°C of three replications of *Lycopersicon esculentum* cultivar Rocket.

Time	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
	Week 4	Week 5	Week 6
9 AM.	19.8 a	24.3 a	9.2 a
12 Noon	10.8 b	6.1 b	6.5 b
3 PM.	20.9 a	14.4 b	9.6 a
Significant at:	1%	5%	1%

Numbers in each column not followed by the same letters are significantly different from each other at the given level of significance as judged by Duncan's new multiple range test.

Table 7. Days to maturity and average respiration at 27°C of three replications of seven cultivars of *Lycopersicon esculentum* adjusted to 9 a.m. values, four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
		Week 4	Week 5	Week 6
Rocket	64	19.8	24.3	9.2
Early Girl	67	19.7	21.7	8.3
Itabec	74	20.5	23.5	9.0
Ultra Girl	77	20.9	24.8	9.1
VFN 8	84	20.5	26.5	9.2
XP 271	92	19.8	23.0	9.6
Redstone	98	20.8	23.3	8.9
Correlation: average respiration and days to maturity		N.S.	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicates no significant difference between cultivars.

Table 8. Days to maturity and average respiration at 27°C of three replications of the first group of three cultivars of *Brassica oleracea* var. *capitata* L., four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
		Week 4*	Week 5	Week 6
Golden Cross	78	62.6	156.9	171.9
Ventura	82	53.3	149.2	170.1
Jet Pak	85	58.3	155.9	167.7
Correlation: average respiration and days to maturity		-0.52	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicates no significant difference between cultivars.

* Significant difference at 5% level from analysis of variance.

Table 9. Days to maturity and average respiration at 27°C of three replications of the second group of three cultivars of *Brassica oleracea* var. *capitata* L., four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt.$^{-1}$·hour^{-1})		
		Week 4	Week 5	Week 6
Golden Cross	78	102.1	75.9	57.3
Earlimart	92	103.3	80.3	60.5
Early Vienna	98	100.4	82.8	56.9
Correlation: average respiration and days to maturity		N.S.	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicates no significant difference between cultivars.

Table 10. Days to maturity and average respiration at 27°C of three replications of the third group of three cultivars of *Brassica oleracea* var. *capitata* L., four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
		Week 4	Week 5	Week 6
Golden Cross	78	95.9	50.5	65.7
Red Head	106	96.4	52.0	68.7
Storage Green	130	100.8	51.6	67.8
Correlation: average respiration and day to maturity		N.S.	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicate no significant difference between cultivars.

Table 11. Relationship between the time of day respiration measurement started and the average respiration at 27°C of three replications of *Brassica oleracea* var. *capitata* L., cultivar Golden Cross.

Time	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
	Week 4 ++	Week 5	Week 6
9 AM.	102.1 a	156.9 a	174.5 a
12 Noon	95.9 a	75.9 b	57.3 b
3 PM.	62.6 b	50.5 c	65.7 b
Significant at:	1%	1%	1%

Numbers in each column not followed by the same letters are significantly different from each other at the given level of significance as judged by Duncan's new multiple range test.

++ In this week only, the 3 p.m. measurement was done one day and the 9 a.m. and 12 noon measurements were done the following day.

Table 12. Days to maturity and average respiration at 27°C of three replications of seven cultivars of *Brassica oleracea* var. *capitata* L., adjusted to 9 a.m. values, four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
		Week 4	Week 5	Week 6
Golden Cross	78	102.1	156.9	174.5
Ventura	82	86.9	149.1	170.3
Jet Pak	85	95.1	155.9	167.7
Earlimart	92	103.3	165.9	181.7
Early Vienna	98	100.5	170.9	173.7
Red Head	106	102.3	162.0	182.3
Storage Green	130	106.9	160.2	180.8
Correlation: average respiration and days to maturity		N.S.	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicated no significant difference between cultivar.

Table 13. Days to maturity and average respiration at 27°C of three replications of the first group of three cultivars of *Beta vulgaris*, four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
		Week 4	Week 5	Week 6
Monogerm	45	33.1	119.4	12.6
Golden	50	33.0	122.1	11.8
Early Wonder	55	33.4	117.4	12.2
Correlation: average respiration and days to maturity		N.S.	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicates no significant difference between cultivars.

Table 14. Days to maturity and average respiration at 27°C of three replications of the second group of three cultivars of *Beta vulgaris*, four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$) Week 4	Week 5	Week 6
Monogerm	45	24.0	21.2	30.0
Cylindra	58	22.7	21.4	29.6
Detroit Dark Red	60	22.9	20.1	31.2
Correlation: average respiration and days to maturity		N.S.	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicates no significant difference between cultivars.

Table 15. Days to maturity and average respiration at 27°C of three replications of the third group of three cultivars of *Beta vulgaris*, four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$) Week 4*	Week 5	Week 6
Monogerm	45	20.8	25.1	8.8
Green Top Bunching	65	19.0	25.1	9.4
Winter Keeper	78	19.9	23.3	9.1
Correlation: average respiration and days to maturity		-0.62	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicates no significant difference between cultivars.

* Significant difference at 5% level from analysis of variance.

Table 16. Relationship between the time of day respiration measurement started and the average respiration at 27°C of three replications of *Beta vulgaris*, cultivar Monogerm.

Time	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
	Week 4	Week 5	Week 6 ++
9 A.M.	33.1 a	119.4 a	30.0 a
12 Noon	24.0 b	21.6 b	8.8 b
3 P.M.	20.8 c	25.1 b	12.6 b
Significant at:	1%	1%	1%

Numbers in each column not followed by the same letters are significantly different from each other at the given level of significance as judged by Duncan's new multiple range test.

++ In this week only, the 3 p.m. measurement was done one day and the 9 a.m. and 12 noon measurements were done the following day.

Table 17. Days to maturity and average respiration at 27°C of three replications of seven cultivars of *Beta vulgaris* adjusted to 9 a.m. values, four to six weeks from germination.

Cultivar	Days to Maturity	Respiration (mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$)		
		Week 4	Week 5	Week 6
Monogerm	45	33.1	119.4	30.0
Golden	50	33.0	122.1	28.4
Early Wonder	55	33.7	117.4	29.1
Cylindra	58	35.3	120.9	29.7
Detroit Dark Red	60	31.3	113.7	31.1
Green Top Bunching	65	30.1	119.7	31.5
Winter Keeper	78	31.7	111.1	30.7
Correlation: average respiration and days to maturity		N.S.	N.S.	N.S.

N.S. Analysis of variance on replicated trials indicated no significant difference between cultivars.

C) Discussion and Conclusions

Of the three species tested for respiration, only one significant correlation with earliness was found. This was in tomato, in the second group of cultivars, during the fifth week from germination. There was only one case in cabbage and one in beet where there was a significant difference between cultivars in the groups, but no significant correlation.

The comparison of the seven cultivars in each species by dividing them into three groups each with a common member, showed no significant difference in leaf respiration. There would have been less opportunity for error if the three groups could have been examined at the same time of day even though this would have required three sets of Warburg respirometers. Equipment limitations necessitated a choice between having replications with fewer cultivars or more cultivars and no replications. Replications with the cultivars in three groups was thought to be the best compromise.

The variation in respiration at different times of the day was so great that a comparison of cultivars in different groups required the assumption that adjusting the values to the common member would not introduce some unforseen error. The earliest maturing cultivar of each species was common to the respective groups and was used to compare the groups. Among species in each week there was a significant difference in respiration at different times of day. In tomato the

respiration was high in the morning, decreasing at noon, and increasing toward late afternoon. Respiration in cabbage was highest in the morning and decreased throughout the day, except at week six where the rate levelled off. Beet was similar except the decrease levelled off in the afternoon at both week five and six. Elliott and Leopold (1952) state maximal differences in respiration among treatments occurred at about midday. The experiment was timed to be as close to midday as possible to maximize differences among cultivars. The measurements in Table 4 which were taken at noon, show a significant difference among cultivars at week five. In both cabbage and beet the only significant differences among cultivars occurred at the 3 p.m. measurement in week four. It appears that maximum difference between cultivars may also occur at midday.

High rates of respiration indicate activity within the plant. Since respiration continues throughout the dark period without the benefit of new substrates from photosynthesis respiration would be at a lower level, and the enzymes would not be working to capacity. By 9 a.m. when the first samples were taken, the plants had been exposed to light for two to three hours. With new substrates and increased temperature, respiration reaches a high point. Temperatures above 20^{o}C can cause limitation of oxygen due to reduced solubility and slow diffusion of gas (Bidwell, 1974). Midday temperatures in the greenhouse often went above 25^{o}C

reducing oxygen availability and therefore decreasing respiration. As the day progressed the temperatures cooled allowing oxygen to be more avaiable and respiration to increase. The species differed in their reactions. In tomato the 3 p.m. respiration rates were as high as the morning rates except week five where they were higher than the midday rates but not as high as the 9 a.m. rates. The 3 p.m. rates for cabbage and beet were either the same or lower than the noon rates which probably depended on the particular temperature of the day the measurement was made.

The three species vary in their relationship between respiration rates and age of plants. In tomato the first run showed a slight increase between weeks four and five and a rapid decrease between weeks five and six. The second run showed a rapid decrease between weeks four and five followed by levelling out between weeks five and six. The third run showed a continuous decrease in respiration rate from weeks four to five to six. The adjusted data in Table 7 showed a slight increase between weeks four and five and a rapid decrease between weeks five and six. If anything can be concluded from this, then it appears that there is a decrease in respiration rate as the leaf matures, although there may be periods of increase during the aging. This may be due to the activity of the rapidly growing leaf requiring more respiration. Once leaf growth stops, respiration can decrease.

In cabbage and beet the time of day the measurements were

taken was not consistent for all three weeks. Since time of day had the largest influence on respiration rate only the adjusted values can be used to determine the relationship between respiration rate and time of day. Cabbage showed a continual increase in respiration rate. This may indicate that the leaves were in a growth phase requiring increased amounts of energy. Red Beet showed an increase in respiration between weeks four and five and a decrease from week five to week six. This may indicate that the leaves were growing between weeks four and five but that leaf growth declined after week five.

On the basis of these experiments it can be concluded that there is no significant difference in respiration rates among cultivars of tomato, cabbage or beet at 27°C. In certain cases there appears to be a difference between cultivars but this is not reliable because the variability for respiration between plants of the same cultivar is greater than the difference between cultivars.

In only three cases was a significant difference found between cultivars of a group, and only once was there a significant correlation with days to maturity. If anything can be concluded from this one case, it would appear to corroborate the thesis given earlier that lower respiration rates in early maturing cultivars tends to be a limiting factor which accelerates the attainment of maturity.

The ability of plants to acclimate should be considered.

The measurements were taken at 27°C which is a temperature which tends to reduce respiration. This high temperature rarely occurs in the field in the spring. Early and late cultivars probably differ in their ability to acclimate to cooler temperatures. Since respiration was only measured at one temperature we cannot tell if early cultivars respire more at lower temperatures. It may be of value to measure respiration rates at much lower temperatures to determine whether differences among cultivars appear.

If further studies were to be done into this aspect, a large number of replications should be performed to minimize the error factor. Sampling should be done in the morning and sufficient equipment used to test all cultivars and replications simultaneously.

There is little real difference between respiraton rates of various cultivars measured at the same time of day at 27°C. The greatest difference is between the time of day the measurement was made. The rate is highest in the morning, decreases toward noon, and may increase again in the late afternoon.

PART TWO

EXAMINATION OF THE RELATIONSHIP BETWEEN PEROXIDASE AND DAYS TO MATURITY

A) Materials and Methods

In this experiment only cabbage and tomato were used. The pigment in Red Beet totally masked any changes from the spectrophotometer.

Germinated seeds only were needed. Germination indicated activation of peroxidase yet no green pigmentation was formed. Individual 10 mm petri dishes for each cultivar were prepared with #2 filter paper moistened with 2 ml of distilled water. Twenty-five uniform seeds of the same lot and package from each of the cultivars were placed in each petri dish. The dishes were randomly placed in a growth chamber under 18 hour photoperiod at 23°C. Three days were sufficient to germinate the minimum 10 seeds needed for the determination. Six replications were done for each cultivar.

Enzyme determination

Ten germinated seeds were taken from each petri dish and weighed.

The seeds were transferred to a mortar and pestle and ground by hand with 15 ml of 1/10 dilute phosphate buffer (Appendix 1). The sample was placed in a closed vial at 2°C for 24 hours. The next day it was filtered, and the filtrate

was used as the sample.

Into a cuvette 1.0 ml of sample, 2.0 ml of phosphate buffer, 0.1 ml H_2O_2 solution, and 0.1 ml p-phenylenediamine solution were pipetted (Appendix One). This was mixed and placed in the spectrophotometer. The optical density (at 485 mμ) was read every 5 seconds for 3 minutes. This was repeated three times with each solution and averaged. The rate constant was calculated:

$K = \Delta E/\Delta T$; where ΔE = change in optical density

ΔT = change in time

K = rate constant at straight line portion

These rates were taken to a common base by dividing by the weight of seeds in the preparation.

B) Results

1. Tomato

Three measurements of peroxidase activity were taken of each replication and averaged to derive the rate per gram of sample. The six replications of the seven cultivars were subjected to the analysis of variance which indicated there was a significant difference at the 1% level. Duncan's multiple range test showed that all cultivars differ significantly except VFN 8 and XP 271.

The correlation coefficient between days to maturity

and peroxidase activity was +0.60. This is not a significant correlation.

Table 18 shows the results and Figure 1 presents them graphically.

2. Cabbage

Similarly three measurements of peroxidase activity were taken of each replication and averaged to derive the rate per gram of sample. The cultivar Early Vienna had very poor germination which made it necessary to delete it from the tests. Two replications of Ventura and two of Earlimart were omitted due to poor germination also. These missing values made the data non-orthogonal and were therefore estimated using the formula:

$$X_{ij} = \frac{tTi + rRj - G}{(t - 1)(r - 1)}$$

where: t = number of treatments (cultivars)

T_i = sum of treatment (cultivar) from which unit is missing

r = number of replicates

R_j = sum of replicate from which unit is missing

G = grand total sum of non-orthogonal design

(Zalik, 1977)

A significant difference was found from the analysis of variance. Duncan's multiple range test was done. A difference was found between Golden Cross and Ventura,

Golden Cross and Storage Green, Ventura and Earlimart, and Earlimart and Storage Green. There was no significant correlation between peroxidase activity and days to maturity ($r = -0.47$).

Table 19 presents the results and Figure 2 is a graphic display.

3. Red Beet

Peroxidase determination depends on measuring the change in absorbance of an indicator in the peroxidase extract. The red pigment in the beet extract totally masked the indicator. Consequently, peroxidase activity of red beet was not determined.

Table 18. Days to maturity and average peroxidase activity for germinated seeds of seven cultivars of *Lycopersicon esculentum* L.

Cultivar	Days to Maturity	Average Peroxidase Activity (K/gram)
Rocket	64	0.0042 e **
Early Girl	67	0.0032 c
Itabec	74	0.0030 b
Ultra Girl	77	0.0026 a
VFN 8	84	0.0038 d
XP 271	92	0.0038 d
Redstone	98	0.0057 f
Correlation between days to maturity and peroxidase activity		+0.60

Analysis of variance on replicated trials indicated a significant difference at the 1% level between cultivars.

** Numbers which are not followed by the same level are significantly different from each other at the 1% level of significance as judged by Duncan's new multiple range test.

Figure 1. Average peroxidase activity for seven cultivars of *Lycopersicon esculentum* L., with their days to maturity.

Cultivar	Days to Maturity
1. Rocket	64
2. Early Girl	67
3. Itabec	74
4. Ultra Girl	77
5. VFN 8	84
6. XP 271	92
7. Redstone	98

(r = +0.60)

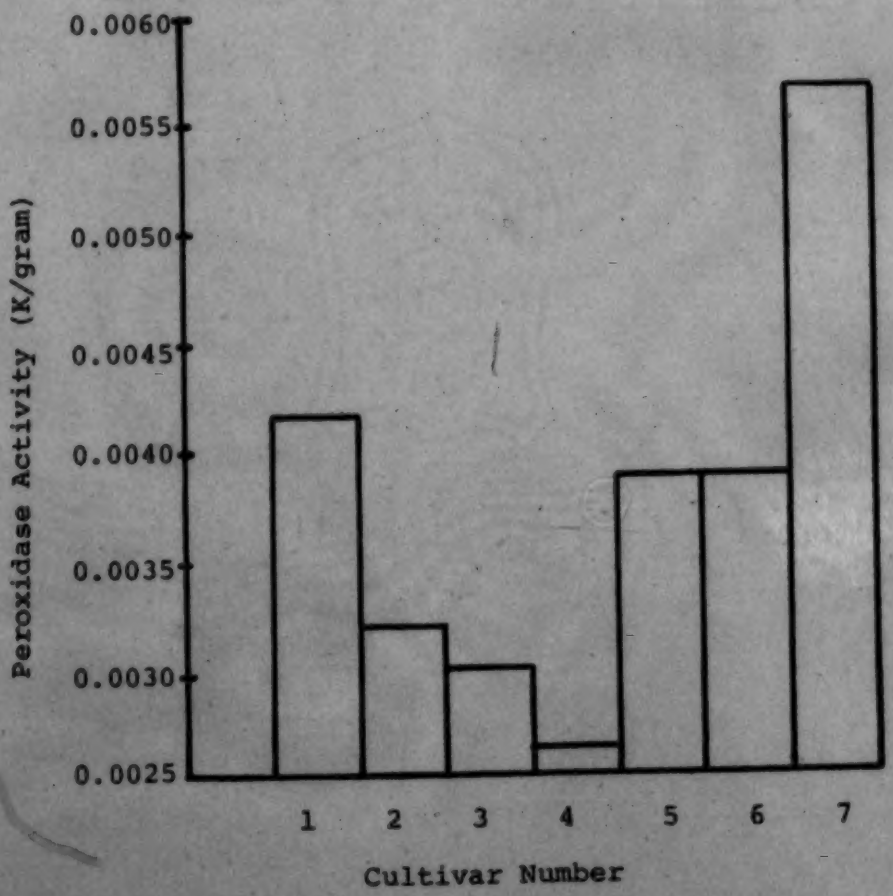


Table 19. Days to maturity and average peroxidase activity for germinated seeds of *Brassica oleracea* var. *capitata* L.

Cultivar	Days to Maturity	Average Peroxidase Activity (K/gram)
Golden Cross	78	0.0210 a b *
Ventura	82	0.0074 c
Jet Pak	85	0.0166 a b c
Earlimart	92	0.0221 a
Early Vienna	98	N/A
Red Head	106	0.0131 a b c
Storage Green	130	0.0082 c
Correlation between days to maturity and peroxidase activity.		+0.47

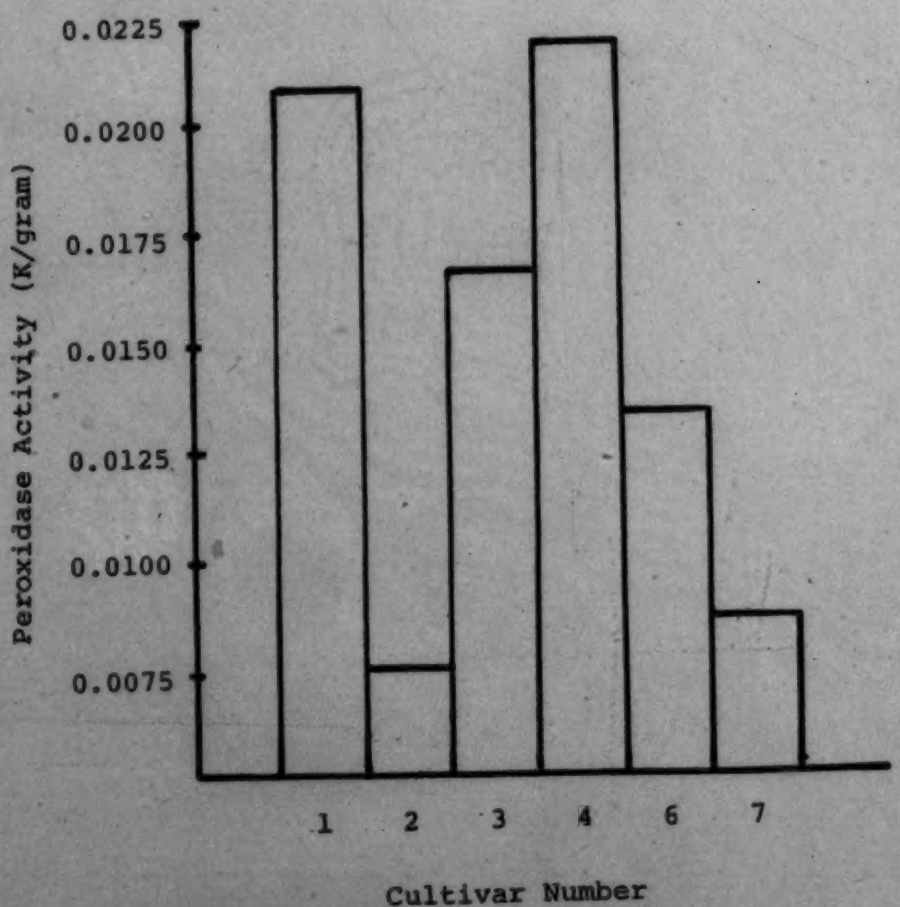
* Numbers which are not followed by the same level are significantly different from each other at the 5% level of significance as judged by Duncan's new multiple range test.

N/A Excluded from trial because of poor germination.

Figure 2. Average peroxidase activity for six cultivars of *Brassica oleracea* var. *captitata* L., with their days to maturity.

Cultivar	Days to Maturity
1. Golden Cross	78
2. Ventura	82
3. Jet Pak	85
4. Earlimart	92
6. Red Head	106
7. Storage Green	130

(r = +0.47)



C) Discussion and Conclusion

Tomato cultivars are significantly different in their peroxidase activity. Cabbage cultivars differ but not to the same extent.

The tendency for peroxidase activity in tomato to decrease as cultivars get later, then to increase in the latest ones, is in contrast to the results of Daskaloff et. al. (1973). They examined the parents and F_1 cross and found peroxidase activity of the F_1 intermediate to the parents. This would be expected as F_1 hybrids are genotypically and usually phenotypically intermediate in most characteristics. They did this with three sets of parents and derived the same result. The earliest parent had the highest peroxidase activity in all three sets. It is not stated whether this was a factor in the selection of parents. They concluded that early cultivars and F_1 crosses have higher peroxidase activity than later cultivars.

This conclusion has not been confirmed by this experiment. The peroxidase activity in tomatoes is at its lowest in the mid-season cultivars and high in the earliest and latest. This pattern may simply be a chance happening because of the cultivars selected.

If peroxidase activity is greater then there must be more breakdown of compounds. Peroxidase may have two modes of action if the pattern shown in tomato is not simply chance. In the early cultivars peroxidase may be causing

the oxidation of some important factor which may become limiting. This limiting factor may be responsible for the early onset of maturity. Activity again increases in the late maturing cultivars and is ultimately greater in the latest. This may be an indication of a more general distribution of peroxidase affecting various aspects of metabolism resulting in a general slow down of reactions leading to maturity. The midseason cultivars have little activity which may indicate that neither limiting action is significant. Kaur-Sawhney and Galston (1972) indicate that indoleacetic acid inhibits peroxidase formation by promoting the formation of a ribonuclease sensitive macromolecular repressor of peroxidase formation. They demonstrated that kinetin opposed this. Bidwell (1974) states that peroxidase activity has regulatory control of IAA. These interactions may be partly involved in the hypothesized relationship between peroxidase activity and maturity in tomato.

If the above proposal is valid it would be so only in species where maturity is judged on the bases of flowering and fruiting. The pattern of peroxidase activity in cabbage in not similar to tomato. Here, cultivars differ in activity but it appears to be random. Perhaps, if the cultivars were ranked in order of flowering and seed formation, a pattern similar to tomato might result.

These results are not in agreement with the work of

Daskaloff et. al. (1973) who indicate a negative correlation between days to maturity and peroxidase activity. Cultivars do, however, differ in peroxidase activity. At present, this method has little value in predicting earliness. There is no indication that peroxidase activity should be further examined in relationship to earliness.

PART THREE

EXAMINATION OF THE RELATIONSHIP BETWEEN NET ASSIMILATION AND DAYS TO MATURITY

A) Materials and Methods

The three species involved were germinated and pricked out into pots as described in the General Experimental Procedure. The pots were transferred from the greenhouse to a growth chamber. It was an Environmental Growth Chambers type, Model M11 with banks of fluorescent and incandescent lights as well as two multivapor and four lucalux lamps. The plants were given about 0.045 $cal \cdot cm^{-2} \cdot min^{-1}$ of cool white fluorescent and incandescent light at a 4:1 ratio for 16 hours per day. The temperature was 18°C at night, 20°C during the day, with a relative humidity of 70%. Additional fertilization was necessary as deficiency symptoms quickly appeared.

Apparatus

The above ground portions of the plants were sealed into a plexiglass cuvette. The cuvette had attachments by which air of known CO_2 concentration (approximately 300 ppm.) could be moved across the leaves. It also had a water jacket around the sides to remove heat generated by the lights. A thermometer was sealed inside and the temperature maintained

at 24°C. The flow of air was measured, passed through a dehydrator, then into an MSA Model 200 LIRA Infared Gas Analyzer. At the same time a reference gas of nitrogen was passed through another flow meter and dehydrator and into the reference cylinder of the gas analyzer (see Figure 3). The flow of sample and reference gas was the same, 1900 ml/min.

Chamber lights could control intensity up to 0.073 $cal \cdot cm^{-2} \cdot min^{-1}$.

Above the cuvette, a quartz halogen lamp and water jacket was suspended. By changing the lamp's height above the cuvette, 0.264 $cal \cdot cm^{-2} \cdot min^{-1}$ could be obtained at plant level.

Analysis

The IRGA was warmed up for at least 30 minutes to allow a controlled temperature to be reached. The IRGA was zeroed and spanned using 300 ppm. CO_2 air (Mayo, et. al., 1973).

Plants were analyzed at eight weeks from germination. A plant was selected and sealed into the cuvette. The temperature and light intensity was set. The measurements started at 0.182 $cal \cdot cm^{-2} \cdot min^{-1}$. Levels of 0.064 and 0.023 $cal \cdot cm^{-2} \cdot min^{-1}$ were also used. The graph first deflected up, then down and levelled off usually after 30 minutes. The plant was removed. The IRGA was zeroed and the cuvette was fanned for one minute to restore CO_2 to ambient levels. The process was repeated.

One replication of all seven cultivars was done first, followed by other replications. They are true replications although they were done at slightly different times. All

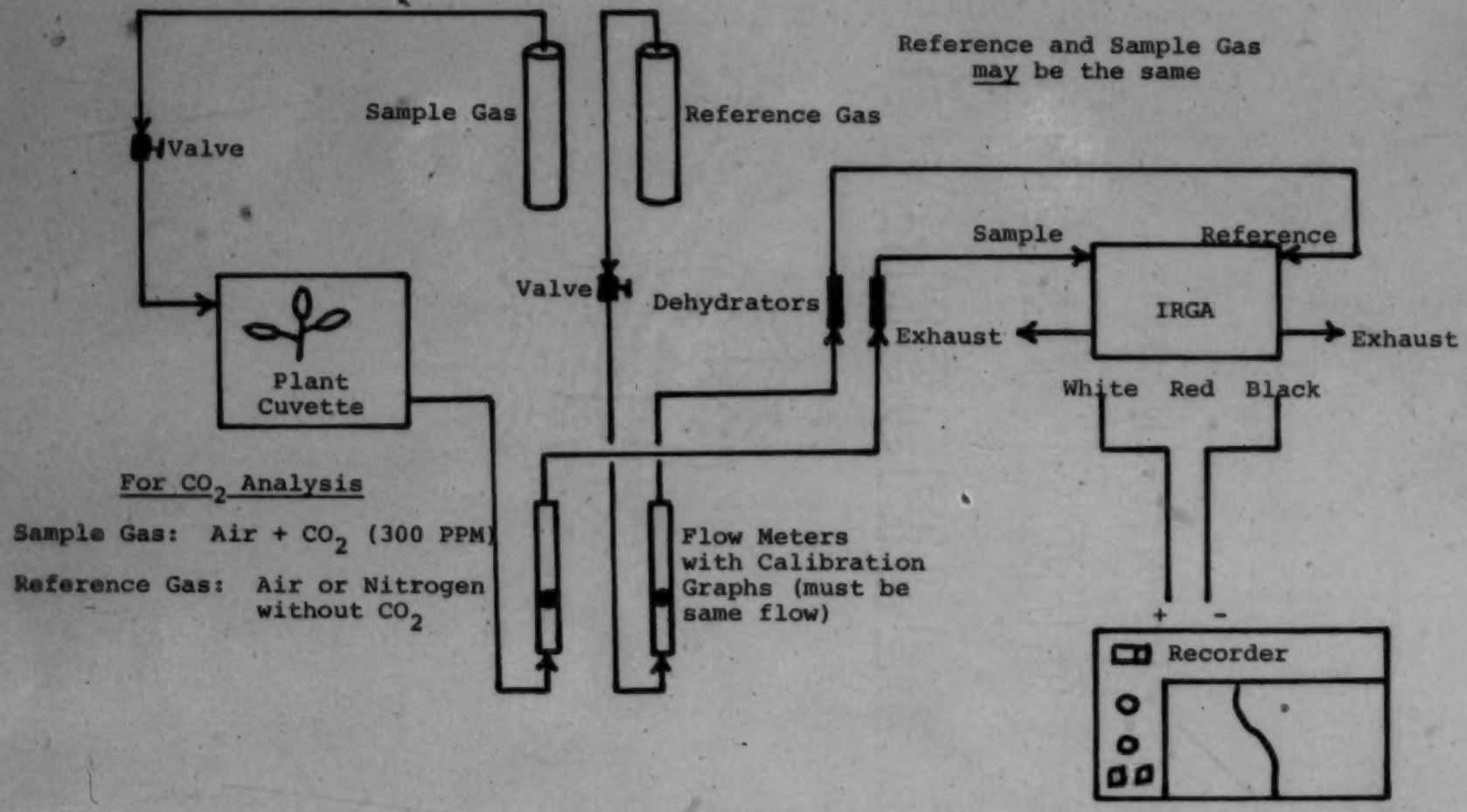


Figure 3. Open System to Measure CO_2 Uptake

measurements of a species were done in one 24 hour period.

The leaves, after the analysis, were taken off without the petiole and had their area measured by an electronic area meter (Automatic Area Meter, Type AAM-5, Hayash:Denko Co. Ltd., Japan). Next the leaves were dried in a constant temperature oven at 75°C for 15 hours. The dry weight was determined in an analytic balance. Lack of availability of facilities limited the scope of the experiment.

B) Results

This experiment was patterned after Badani (1974) but included replications to provide some statistical backing.

Net assimilation was expressed in two ways. First it was expressed in terms of milligrams of CO_2 fixed per minute per gram of dry weight of leaf tissue, and secondly as milligrams of CO_2 fixed per minute per square centimeter of leaf tissue.

1. Tomato

No significant difference in net assimilation rates was found among tomato cultivars at either 0.073 or 0.182 $cal \cdot cm^{-2} \cdot min^{-1}$ light intensity. Also, cultivars appeared to have little response to increased light intensity. This was true for both measurements in terms of dry weight and leaf

area. See Appendix Three for detailed data.

Results are shown on Tables 20 and 21.

2. Cabbage

Net assimilation of cabbage was measured at 0.064 $cal \cdot cm^{-2} \cdot min^{-1}$ light intensity only due to lack of facilities. No significant difference was found in terms of dry weight or leaf area.

Results are shown on Tables 22 and 23.

3. Beet

Net assimilation of beet was measured at 0.023 and 0.064 $cal \cdot cm^{-2} \cdot min^{-1}$. Again, no significant difference was found in terms of dry weight or leaf area.

There does appear to be a definite increase in net assimilation at the higher light intensity.

Results are shown in Tables 24 and 25.

In all three species seven cultivars were grown. During their growth nitrogen and phosphorus deficiencies developed very rapidly, which in some cases increased fertilization did not completely correct. An aphid infestation did some damage. As will be noted in the tables, not all seven cultivars of each species are shown. Only uniform, healthy plants were measured. This not only reduced the number of cultivars measured but reduced the replications from five to three.

Table 20. Days to maturity and average net assimilation at 24°C per gram dry weight of leaf of three replications of *Lycopersicon esculentum* L. at two light intensities.

Cultivar	Days to Maturity	Net Assimilation (mg $CO_2 \cdot gram^{-1} \cdot hr^{-1}$)	
		0.073 $cal \cdot cm^{-2} \cdot min^{-1}$	0.182 $cal \cdot cm^{-2} \cdot min^{-1}$
Rocket	64	N/A	3.07
Early Girl	67	3.38	N/A
Itabec	74	3.07	N/A
Ultra Girl	77	3.48	2.24
VFN 8	84	3.47	2.85
XP 271	92	2.81	N/A
Redstone	98	2.69	2.85

Analysis of variance on replicated trials indicates no significant difference between cultivars.

N/A: It was not possible to test this cultivar.

Table 21. Days to maturity and average net assimilation at 24°C per unit leaf area of three replications of six cultivars of *Lycopersicon esculentum* L. at two light intensities.

Cultivar	Days to Maturity	Net Assimilation (mg $CO_2 \cdot dm^{-2} \cdot hour^{-1}$)	
		0.073 $cal \cdot cm^{-2} \cdot min^{-1}$	0.182 $cal \cdot cm^{-2} \cdot min^{-1}$)
Rocket	64	N/A	1.58
Early Girl	67	1.66	N/A
Itabec	74	1.74	N/A
Ultra Girl	77	1.74	1.14
VFN 8	84	2.54	1.96
XP 271	92	1.65	N/A
Redstone	98	1.58	1.67

Analysis of variance on replicated trials indicates no significant difference between cultivars.

N/A: It was not possible to test this cultivar.

Table 22. Days to maturity and average net assimilation at 24°C per gram dry weight of leaf of three replications of *Brassica oleracea* var. *capitata* L. at 0.064 cal·cm^{-2}·min^{-1}.

Cultivar	Days to Maturity	Net Assimilation (mg CO_2·gram^{-1}·hour^{-1})
		0.064 cal·cm^{-2}·min^{-1}
Golden Cross	78	3.59
Jet Pak	85	3.73
Storage Green	130	4.22

Analysis of variance on replicated trials indicates no significant difference between cultivars.

Table 23. Days to maturity and average net assimilation at 24°C per unit leaf area of three replications of three cultivars of *Brassica oleracea* var. *capitata* L. at 0.064 cal·cm^{-2}·min^{-1}.

Cultivar	Days to Maturity	Net Assimilation (mg CO_2·dm^{-2}·hour^{-1}) at 0.064 cal·cm^{-2}·min^{-1}
Golden Cross	78	2.92
Jet Pak	85	2.98
Storage Green	130	3.10

Analysis of variance on replicated trials indicates no significant difference between cultivars.

Table 24. Days to maturity and average net assimilation at 24°C per gram dry weight of leaf of three cultivars of *Beta vulgaris* at two light intensities.

Cultivar	Days to Maturity	Net Assimilation (mg $CO_2 \cdot gram^{-1} \cdot hour^{-1}$)	
		0.023 $cal \cdot cm^{-2} \cdot min^{-1}$	0.064 $cal \cdot cm^{-2} \cdot min^{-1}$
Mono Germ	45	1.34	8.90
Detroit Dark Red	60	1.63	9.49
Winter Keeper	78	3.98	8.62

Analysis of variance on replicated trials indicates no significant difference between cultivars.

Table 25. Days to maturity and average net assimilation at 24°C per unit leaf area of three replications of three cultivars of *Beta vulgaris* at two light intensities.

Cultivar	Days to Maturity	Net Assimilation (mg $CO_2 \cdot dm^{-2} \cdot hour^{-1}$)	
		0.023 $cal \cdot cm^{-2} \cdot min^{-1}$	0.064 $cal \cdot cm^{-2} \cdot min^{-1}$
Mono Germ	45	0.77	5.33
Detroit Dark Red	60	0.83	4.84
Winter Keeper	78	2.64	5.74

Analysis of variance on replicated trials indicates no significant difference between cultivars.

C) Discussion and Conclusions

The assimilation experiments produced only a very brief outline of results due to not having the necessary equipment for sufficient time. It was intended to enlarge the scope of Badani's (1974) experiments which were similar. This enlargement was done by having replications, and seven cultivars of tomatoes, three of cabbage and three of beet. Equipment limitations resulted in measuring the replications consecutively instead of simultaneously.

Other experimenters have used one detached leaf to measure assimilation assuming it would be a meaningful average for the entire plant. This researcher felt that measuring the assimilation by the entire above ground portion of the plant would be better. The leaves were not detached and effects due to self shading were not changed. It is felt that this would give a more realistic average of the rate of assimilation on living plants.

The results were calculated in terms of leaf area and dry weight of leaves to see which would be more precise.

The largest variable in the experiments was the health of the plants. Their rate of growth in the growth chamber was much faster than it would have been in a greenhouse or field. Nutrient deficiency symptoms often appeared overnight. To minimize this variability these plants were eliminated and only apparently healthy ones were used. This reduced the number of replications and cultivars used.

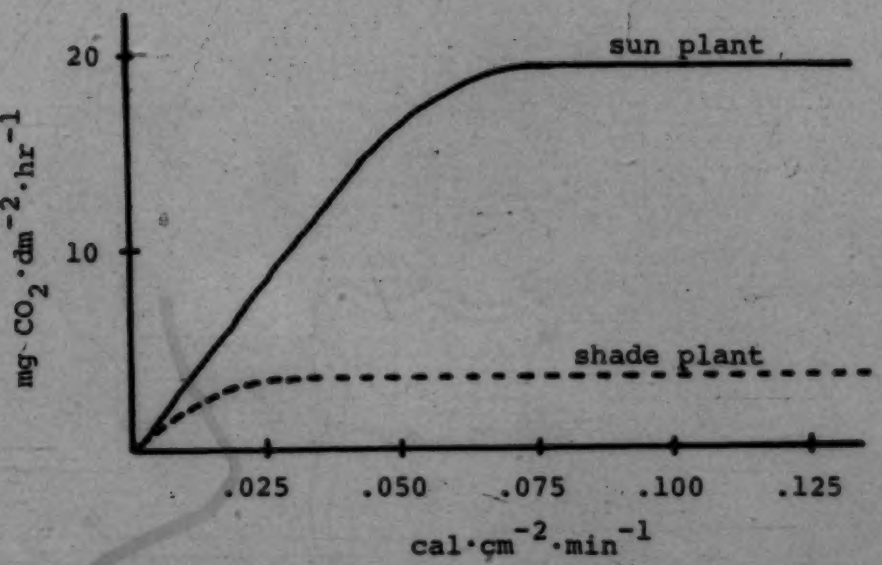
The results of these experiments showed no significant difference in net assimilation between cultivars. Net assimilation did change with light intensity.

The tomato cultivars were subjected to a 2.5 times increase in light energy. Net assimilation by Ultra Girl and VFN 8 decreased as light energy increased. The change was very slight. Redstone did not change. This indicates that the increased light was insufficient to change net assimilation. Badani (1974) with his three tomato cultivars found a doubling of net photosynthesis within the same light range. His were grown under natural sunlight and transferred to the different light intensities in the growth chamber.

Bohning and Burnside (1956) present the following graph showing the difference between sun and shade species (Figure 4).

Part of the difference may arise from the ability of the tomato plant to adapt to different light conditions. The plants grown in full sunlight may be responding to light intensities as do sunplants which have a much higher saturation point than do shade plants. The tomatoes grown in the less intense light of a chamber may be responding as shade plants having a much lower saturation point. If this is true then it would explain why there was no increase in net assimilation. The plants already had reached the saturation point.

Figure 4. Net assimilation by sun and shade plants



From Bohning and Burnside (1956)

Red beets responded to the increased light intensity by nearly tripling in net assimilation. At 0.023 cal·cm^{-2}·min^{-1} the early cultivars had less net assimilation than did the latest but only if the analysis of variance was performed at the 10% level of significance. It is bordering on being significantly different. As light intensity increased there was a much greater increase in net assimilation in the earlier cultivars than in the latest (5.8 times as opposed to 2.2 times). At the highest light level there were no difference in cultivars at any level of significance. From this we may find that beet cultivars vary the most in net assimilation at low light levels. This would take further

research to confirm. If the results were extrapolated to higher light intensities then it would appear that the earlier cultivars would have higher net assimilation.

Measurement of net assimilation in terms of leaf area rather than dry weight appears to be preferred. In the case of beet there was a significant difference at 10% using leaf area at 0.023 $cal \cdot cm^{-2} \cdot min^{-1}$ whereas using dry weight there was no difference at any level. A thick heavy leaf could have the same net assimilation as a thin one of the same area, but dividing by dry weight would cause it to appear different or vice versa.

If this experiment was to be repeated then some changes should be made. Plants should be grown under natural sunlight and transferred to the controlled growth chamber environment only for measurements, or they should be grown at higher light intensities in the growth chamber.

The natural variability between plants of the same cultivars could be somewhat offset by having more replications.

Net assimilation has no value at these light levels and this temperature in predicting the degree of vegetative earliness as there is no significant difference between cultivars. Measuring net assimilation in terms of leaf area is better than in terms of leaf area is better than in terms of dry weight. Tomato did not respond to the small increase in light intensity whereas beet did.

PART FOUR

EXAMINATION OF THE RELATIONSHIP BETWEEN LEAF AREA AND DAYS TO MATURITY

A) Materials and Methods

All 21 cultivars were grown in the greenhouse in the winter of 1978 as outlined in the General Experimental Procedures. The temperature was kept at 16°C at night and supplemental fluorescent lighting provided a 14 hour photoperiod. The plants were divided into five replications which were randomized on the bench to minimize micro-environmental influences.

Cabbage and beet cultivars were measured at three, four and five weeks from germination. Tomato was measured at three and seven weeks from germination.

Measurement

Plants were to be measured as they grew over a period of weeks. This meant that the plant must not be damaged. The leaves were photographed while still on the plant. They were not removed so the plants could be returned to the greenhouse for further growth. Only one set of tomato plants (seven cultivars with five replications) was used but the leaves were measured twice at three and seven weeks. Similarly one set each of cabbage and beet were grown and were measured

three times each, at three, four and five weeks.

Photographic facilities were set up in a darkroom. A microscope lamp was used as a directed light source. In the dark the selected leaf was placed in contact with unexposed photographic paper. The light was momentarily turned on to expose a silhouette of the leaf. The photograph was developed by standard processes: developer, stop-bath and hypo. The result was a white image the same size as the leaf. This image was cut out and put through an electric area meter (Automatic Area Meter, Type AAM-5, Hayash:Denko Co. Ltd., Japan). This was repeated for all five replications. All measurements from a species were done within one day.

B) Results

Five replications of seven cultivars of each of three species were grown. No significant correlation between earliness and leaf area was found. However, certain relationships were found as noted below.

1. Tomato

Leaf area was measured at three and seven weeks, but only at seven weeks was there a significant difference between cultivars. At week three there was great variability among replications. At week seven, Ultra Girl, the middle cultivar in the maturity range, had a much higher leaf area. The

other cultivars, both earlier and later, were significantly different from Ultra Girl at the 5% level as judged by Duncan's new multiple range test. XP 271 had the lowest leaf area.

Results are shown in Table 26 and Figure 5.

2. Cabbage

Leaf area measurements were taken at three, four and five weeks from germination. Cultivars were significantly different in leaf area at the 1% level in all three periods. At week three Ventura, Jet Pak and Earlimart, the second, third and fourth cultivars in order of maturity were significantly greater in leaf area at the 1% level than both earlier and later cultivars. The earliest and latest cultivars did not differ significantly.

At week four, Earlimart, the fourth cultivar in order of maturity, had the greatest leaf area. Earlier cultivars had a smaller leaf area and later ones the smallest.

Results are presented in Table 27 and Figure 6.

3. Beet

Leaf area measurements were taken at three, four and five weeks. No significant differences were found among cultivars in weeks three and four. At week five Burpee's Golden, the second cultivar, had the smallest leaf area. Mono Germ, Detroit Dark Red and Winter Keeper, the first,

fifth and seventh cultivars in order of maturity, had the greatest leaf area. The other cultivars were in the middle range leaf area.

Results are shown in Table 28 and Figure 7.

Table 26. Relationship between days to maturity and average total leaf area of five replications of seven cultivars of *Lycopersicon esculentum* L. at three and seven weeks from germination.

Cultivar	Days to Maturity	A Total Leaf Area (cm^2) Week 3	Week 7*
Rocket	64	9.14 a (1)	485.43 a b
Early Girl	67	14.73 a	637.98 a
Itabec	74	10.83 a	501.26 a b
Ultra Girl	77	17.90 a	905.37 c
VFN 8	84	15.38 a	605.81 a
XP 271	92	13.42 a	437.59 b
Redstone	98	10.56 a	479.32 a b

* Numbers in this column not followed by the same letters are significantly different from each other at the 5% level as judged by Duncan's new multiple range test.

(1) Appendix Four shows variability in data.

Figure 5. Average total leaf area and days to maturity of seven cultivars of *Lycopersicon esculentum* L. at three and seven weeks from germination.

Cultivar	Days to Maturity
1. Rocket	64
2. Early Girl	67
3. Itabec	74
4. Ultra Girl	77
5. VFN 8	84
6. XP 271	92
7. Redstone	98

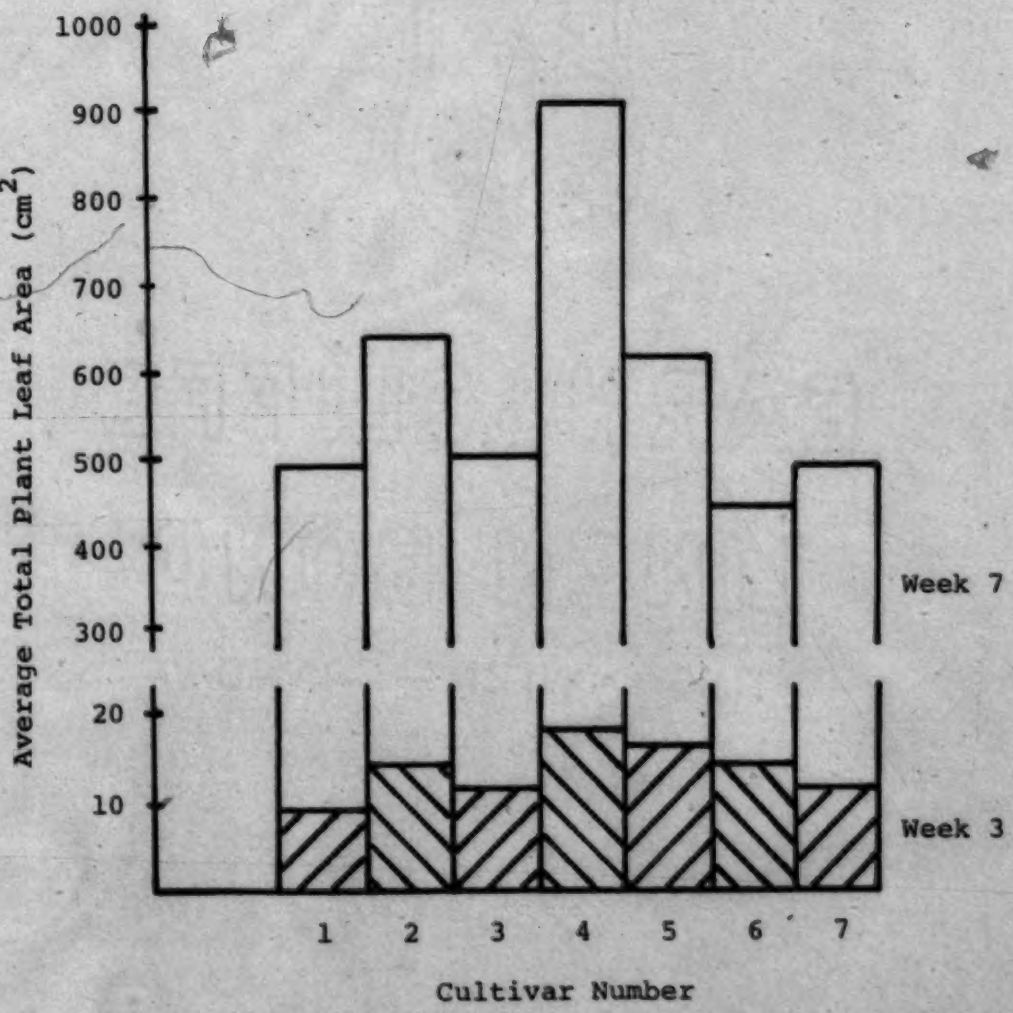


Table 27. Relationship between days to maturity and average total leaf area of five replications of seven cultivar of *Brassica oleracea* var. *capitata* L. at three, four and five weeks from germination.

Cultivar	Days to Maturity	Average Total Leaf Area (cm^2) Week 3 **	Week 4 **	Week 5 **
Golden Cross	78	12.45 a	84.90 a c	508.81 a
Ventura	82	17.43 b	103.38 a	571.51 a
Jet Pak	85	17.33 b	107.58 a	574.99 a
Earlimart	92	18.67 b	148.01 b	775.68 b
Early Vienna	98	10.98 a	77.50 a c	490.43 a
Red Head	106	10.74 a	58.98 c	460.16 a
Storage Green	130	11.95 a	85.40 a c	584.04 a

** Numbers in this column not followed by the same letters are significantly different from each other at the 1% level as judged by Duncan's new multiple range test.

Figure 6. Average total leaf area and days to maturity of seven cultivars of *Brassica oleracea* var. *capitata* L. at three, four and five weeks from germination.

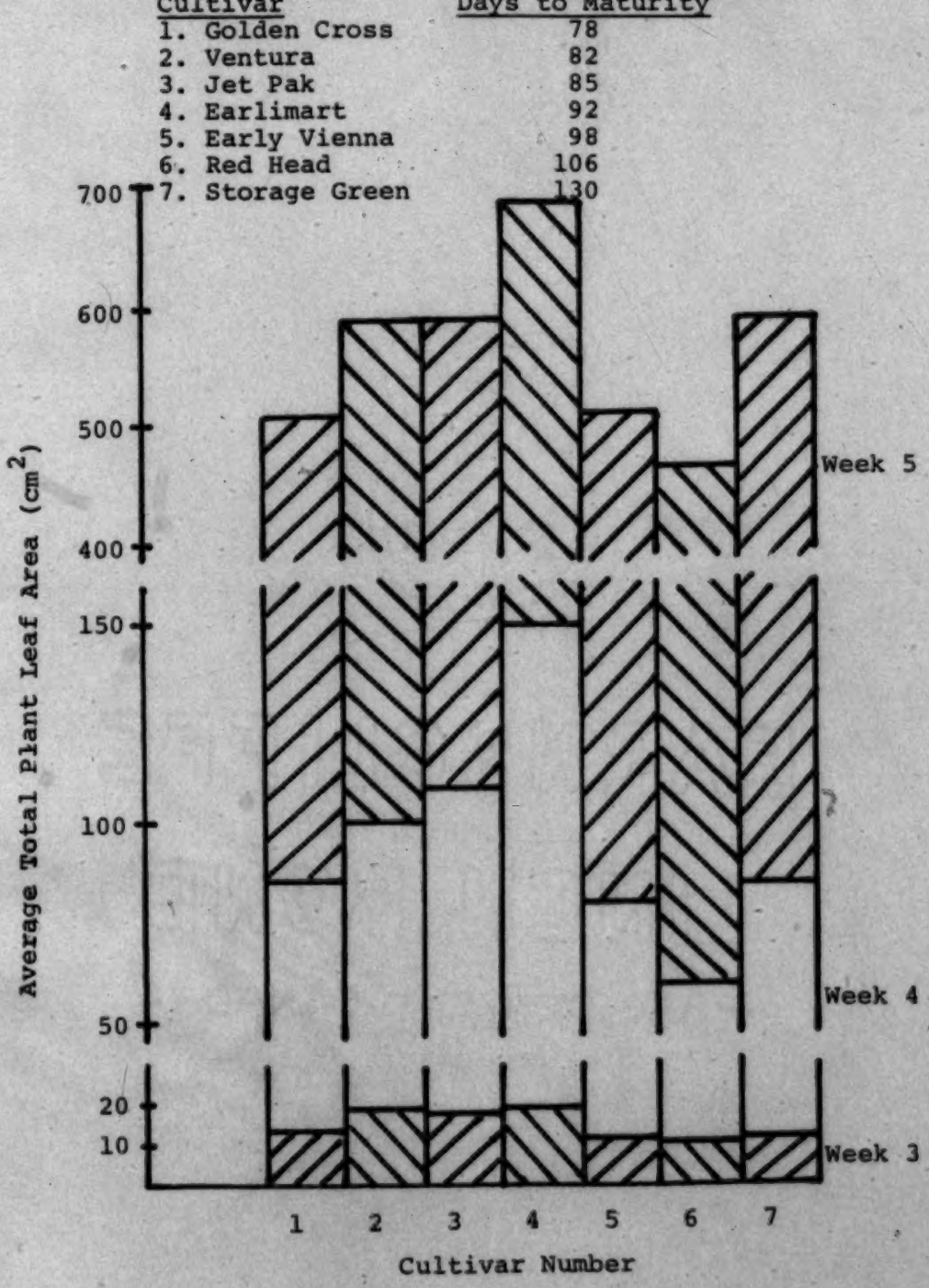


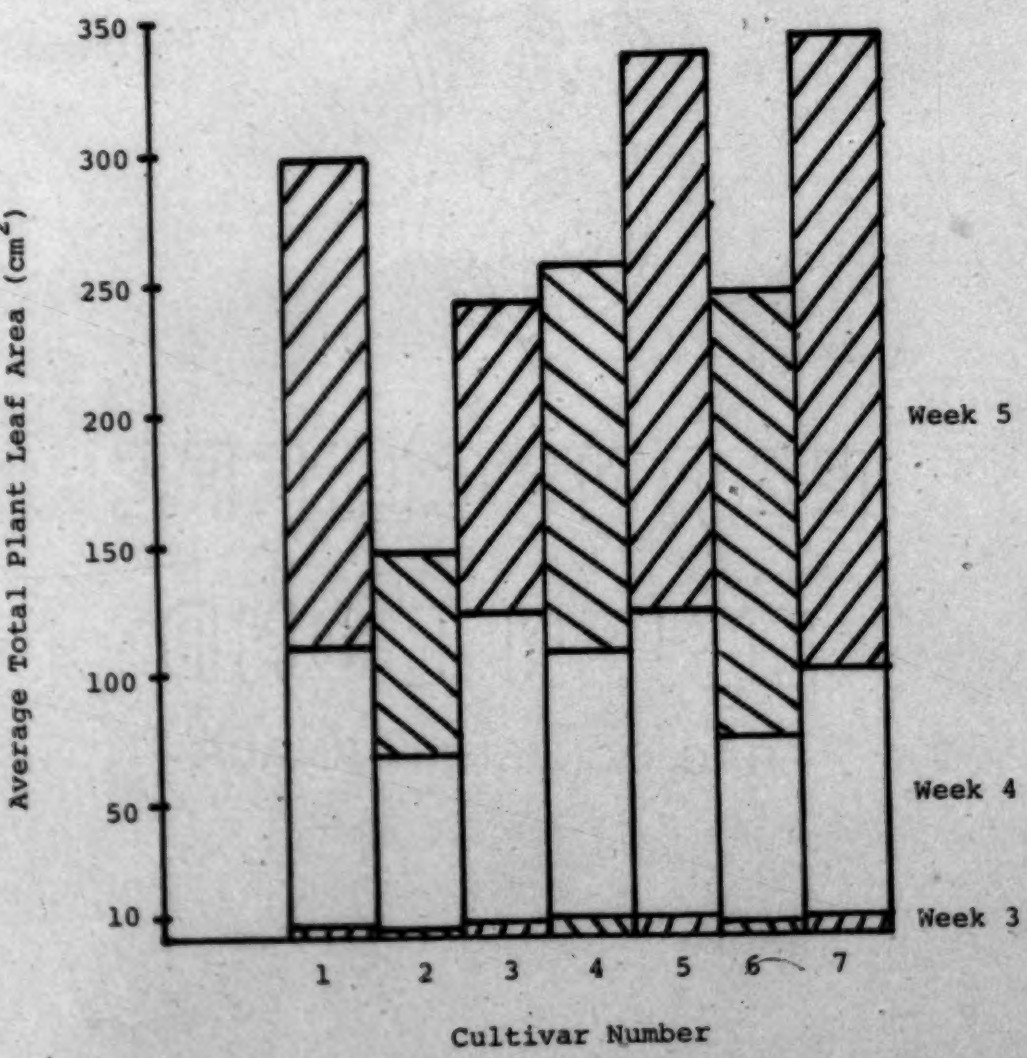
Table 28. Relationship between days to maturity and average total leaf area of five replications of seven cultivars of *Beta vulgaris* at three, four and five weeks from germination.

Cultivar	Days to Maturity	Average Total Leaf Area (cm^2)		
		Week 3	Week 4	Week 5 **
Mono Germ	45	5.42 a	111.78 a	298.01 a
Burpee's Golden	50	3.58 a	68.77 a	145.73 b
Early Wonder	55	6.22 a	121.28 a	238.64 a b
Cylindra (Formonova)	58	6.86 a	107.20 a	255.90 a b
Detroit Dark Red	60	6.73 a	121.00 a	333.09 a
Green Top Bunching	65	5.92 a	72.43 a	247.15 a b
Winter Keeper	78	7.19 a	97.70 a	337.52 a

** Numbers in this column not followed by the same letters are significantly different from each other at the 1% level as judged by Duncan's new multiple range test. Week three and week four were not significantly different at the 5% level.

Figure 7. Average total leaf area and days to maturity of seven cultivars of *Beta vulgaris* at three, four and five weeks from germination.

Cultivar	Days to Maturity
1. Mono Germ	45
2. Burpee's Golden	50
3. Early Wonder	55
4. Cylindra	58
5. Detroit Dark Red	60
6. Green Top Bunching	65
7. Winter Keeper	78



C) Discussion and Conclusions

No correlation between leaf area and days to maturity was found. However, the data for tomato and cabbage suggests a trend. The leaf area of the tomatoes increased from cultivars one to four except for cultivar three and decreased from cultivars four to seven except cultivar six in week seven. Week three of tomato growth showed this trend the best. Similarly this trend appears at week four and five in cabbage. Leaf area increased from cultivars one to four and decreased from four to six. Cultivar seven was an exception. In red beet at week five, this trend appears to be present with exceptions. Leaf area increased from cultivar two to five and decreased from five to six. The exceptions, cultivars one and seven, could possibly follow this trend if a very large number of replications were performed. The original data in Appendix Four for beet in week five shows that there were some values much below the average obtained for those five particular plants chosen to represent cultivar one and seven. These data cannot prove the trend but there is an indication.

As mentioned earlier, Gregory (1928) claims a relationship between nitrogen supply and leaf area. The shoots supply carbohydrates to the roots. The root growth increases and supplies more nitrogen to the shoot for leaf growth. This may indicate more nitrogen being supplied to the midseason cultivars. Nitrogen is known for increasing lush vegetation,

decreasing fruit production, and delaying the maturation process (Bidwell, 1974). Conversely, low nitrogen levels reduce the size of the plant.

Phosphorus levels affect all aspects of plant metabolism and growth. If deficient, plants develop slowly and maturity is delayed (Bidwell, 1974 and Knott, 1957).

Pandita (1966) found a high negative correlation between phosphorus content of the leaves and days to maturity in tomato, lettuce and cabbage. Radish, a root crop, had a positive correlation.

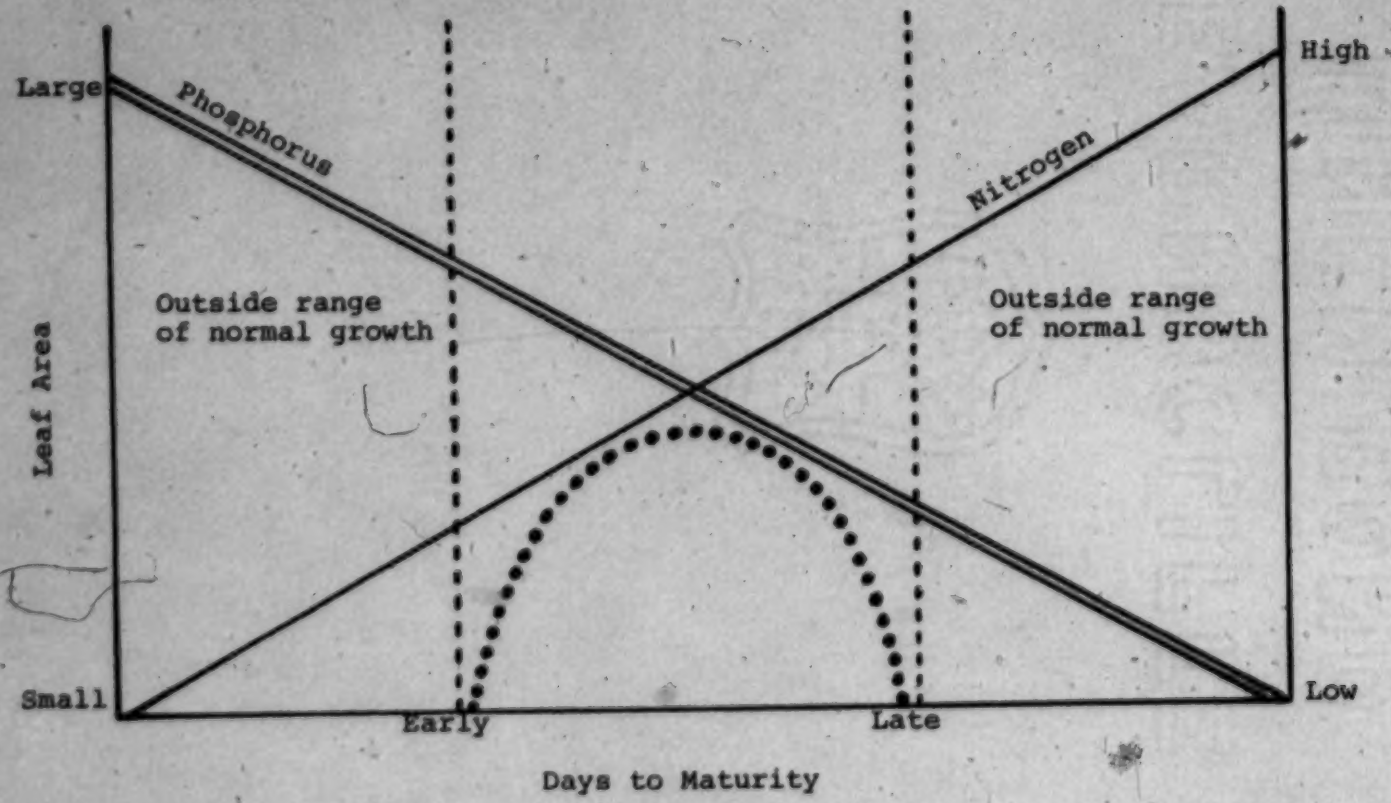
Casement (1975) examined the relationship between nitrogen content of the plant and days to maturity. Positive, but not strong, correlations were found.

Figure 8 shows a theorized relationship between leaf area, nitrogen, phosphorus and days to maturity.

Figure 8 is an attempt to picture the known facts. In early maturing plants phosphorus is high, nitrogen is low and leaf area is small. Low nitrogen tends to reduce vegetative growth and may also become a limiting factor which may accelerate maturation. Phosphorus, being high, also accelerates maturation. The result is an early plant with small leaf area.

In late maturing plants, nitrogen is high and phosphorus is low. These factors both work to delay maturity and as they become more pronounced the rate of maturation becomes slower. As noted above, low phosphorus levels slow plant

Figure 8. Theorized relationship between leaf area, nitrogen, phosphorus and days to maturity in first weeks of growth.



●●●●●●● Idealized curvilinear relationship of Leaf Area and Days to Maturity

development which means that even though nitrogen is high, the growth of the plant and consequently leaf area, is reduced. As the plant develops the overall amount of phosphorus increases. Since it is mobile it can be accumulated in areas where it is needed for growth and therefore its inhibition on growth is decreased. The high nitrogen levels eventually start leaf area increasing.

Midseason cultivars have nitrogen and phosphorus levels between the early and late cultivars. The effects of these two elements would be between their effects on early and late cultivars. Nitrogen would be moderately high and phosphorus would not be low enough to slow down growth. The result would be a large leaf area. The days to maturity would be longer than the early cultivars because of the effects of the lower phosphorus and higher nitrogen level. The days to maturity would not be as great as in the latest cultivars because the delaying action of very high nitrogen would not be present.

The beet cultivars generally showed the same trends but no known measurements of nitrogen and phosphorus levels in cultivars varying in days to maturity have been done. Beets, being a root crop may react differently. It is interesting to note Pandita's (1966) phosphorus measurements of the root crops (radish) showed a positive correlation. This may have some relation to the needs of the storage root.

The area of the leaf must contribute to maturity in some way because the processes of photosynthesis, assimilation,

respiration, etc. occur within it.

There appears to be some indication that leaf area is greatest in midseason cultivars. This may be due to the opposing interaction of nutritive elements: nitrogen and phosphorus. These two elements are suspected of having some regulation of maturation. The leaf area of the plant will have some influence on the amount of enzymatic processes occuring within it. These factors together may contribute to controlling how long it takes a plant to reach maturity.

It would be simplistic to ignore the numerous other factors controlling size, such as other nutrients, photosynthetic efficiency etc. The suggested relationship between days to maturity and leaf area will always be subject to these other factors and therefore its efficiency in predicting days to maturity will be reduced.

PART FIVE

EXAMINATION OF THE RELATIONSHIP BETWEEN SHOOT:ROOT RATIO AND DAYS TO MATURITY

A) Materials and Methods

All 21 cultivars of the three species were used. The plants were to be sampled at three, five and seven weeks from germination. Four replications were done. Four relatively uniform plants of each cultivar were harvested at each sampling date.

The cultivars were grown in the greenhouse during the summer of 1978. Transplanting and fertilization followed the General Experimental Procedures section except that Cornell Mix was not used. The peat and vermiculite was replaced by sand and the ground limestone was deleted. The plants were randomly placed to minimize microclimate effects.

The night temperature of the greenhouse was set at 16°C and the natural photoperiod was not supplemented.

Sampling

After the plants had been randomly selected the shoots were cut off at ground level and placed in a beaker. The sand from the root ball was carefully washed through a fine sieve with low water pressure. The clean roots, including those caught by the sieve were placed in a petri dish.

Shoots and roots from each plant sampled were identified and separated from the others and then placed in a drying oven at 75°C for 36 hours. After removal from the oven the dry weight of the shoots and roots was measured on an analytic balance. The shoot:root ratio was calculated. The sampling was done within one day for each species and was repeated at five and seven weeks. All three species were treated similarly.

B) Results

1. Tomato

Shoot:root ratios were measured at three, five and seven weeks but the only significant difference between cultivars was found at week seven. There was an apparent large difference between averages of the four replications (one plant per replication), but the replications were greatly variable which necessitated the conclusion of no significant difference.

Generally there was no difference between weeks three and five, and a small increase in week seven.

During week seven Early Girl, the second earliest cultivar, had the largest ratio and Redstone, the latest cultivar, had the smallest. There was no significant correlation between days to maturity and shoot:root ratio.

Results are presented on Table 29 and Figure 9.

2. Cabbage

Shoot:root ratios were measured at three, five and seven weeks. There were significant differences among cultivars at seven weeks.

Week seven showed differences at the 5% level. Golden Cross, Early Vienna and Red Head, the first, fifth and sixth cultivars in order of maturity had the highest shoot:root ratios. Jet Pak, the third cultivar had the lowest ratio.

There was no correlation between shoot:root ratios and days to maturity.

Between weeks three and five, six of the seven cultivars had higher ratios, and between weeks five and seven, all seven cultivars had higher ratios.

Results are shown in Table 30 and Figure 10.

3. Beet

Shoot:root ratios were measured at three, five and seven weeks. Significant differences among cultivars were found only at week 5 where the difference was significant at the 5% level.

Mono Germ, Green Top Bunching and Winter Keeper, the first, sixth and seventh cultivars in order of days to maturity had the smallest ratios. Detroit Dark Red, the fifth cultivar had the largest ratio. There was no significant correlation between days to maturity and shoot:root ratios.

The results are shown in Table 31 and Figure 11.

Table 29. Days to maturity and average shoot:root ratios of four replications of seven cultivars of *Lycopersicon esculentum* L. at three, five and seven weeks from germination.

Cultivar	Days to Maturity	Shoot:Root		
		Week 3	Week 5	Week 7 *
Rocket	64	2.3916	3.0448	4.1256 a b
Early Girl	67	2.8865	3.0708	5.0172 a
Itabec	74	3.3214	3.3780	4.2149 a b
Ultra Girl	77	2.4693	3.3105	4.0179 a b
VFN 8	84	3.8216	2.7886	3.7191 b
XP 271	92	3.0981	3.5110	4.1059 a b
Redstone	98	2.3793	2.2944	3.3252 b
Correlation between days to maturity and shoot:root ratio		N.S	N.S	-0.72

* Numbers in this column not followed by the same letters are significantly different from each other at the 5% level as judged by Duncan's new multiple range test.

Other columns show no significant difference.

Figure 9. Average shoot:root ratios and days to maturity of seven cultivars of *Lycopersicon esculentum* L. at three, five and seven weeks from germination.

Cultivar	Days to Maturity
1. Rocket	64
2. Early Girl	67
3. Itabec	74
4. Ultra Girl	77
5. VFN 8	84
6. XP 271	92
7. Redstone	98

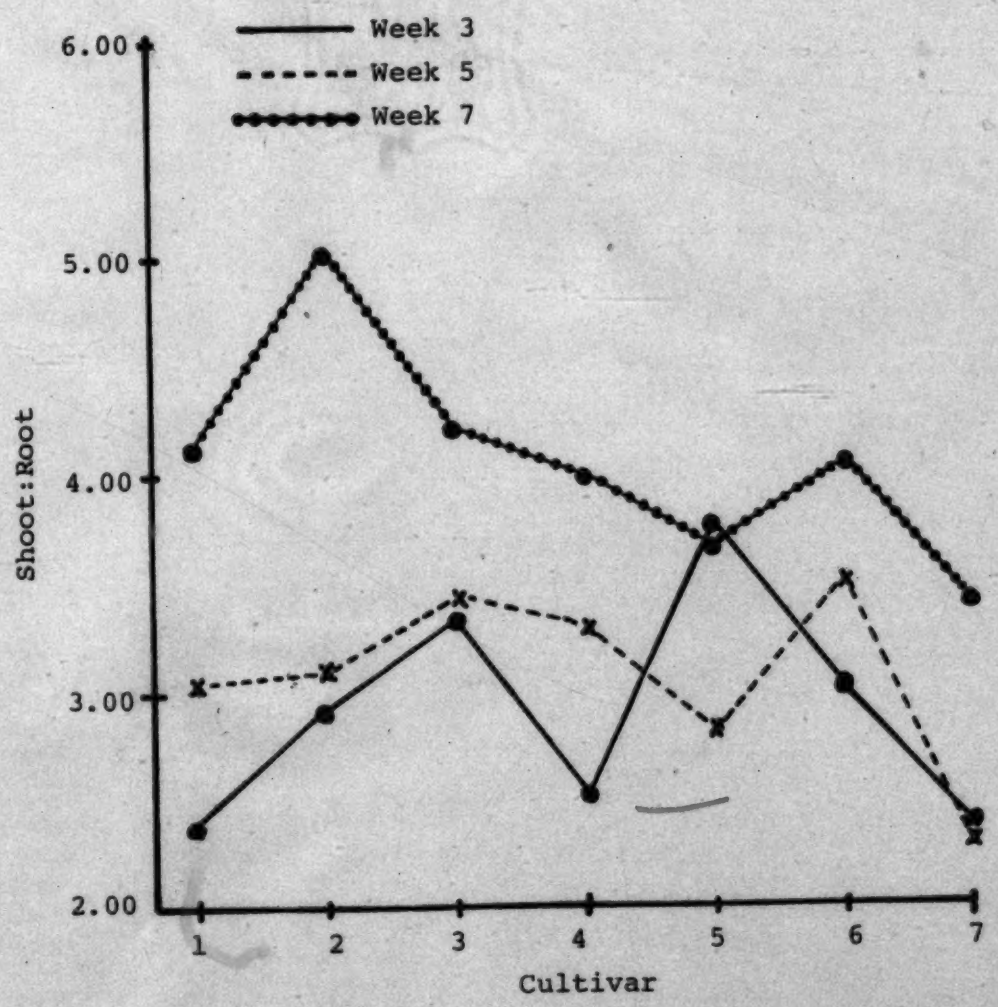


Table 30. Days to maturity and average shoot:root ratios of four replications of seven cultivars of *Brassica oleracea* var. *capitata* L. at three, five, and seven weeks from germination.

Cultivar	Days to Maturity	Shoot:Root Week 3	Week 5	Week 7 *
Golden Cross	78	1.6890	2.8619	5.0609 a
Ventura	82	1.8331	3.1288	4.4189 a b c
Jet Pak	85	2.5576	3.0022	3.8883 c
Earlimart	92	3.3628	3.0548	4.0932 b c
Early Vienna	98	2.1611	2.8053	5.1849 a
Red Head	106	2.1016	3.4072	5.1838 a
Storage Green	130	1.2864	3.6985	4.8229 a b
Correlation between days to maturity and shoot:root ratio		N.S	N.S	+0.33

* Numbers in this column not followed by the same letter are significantly different from each other at the 5% level as judged by Duncan's new multiple range test.

Other columns show no significant difference.

Figure 10. Average shoot:root ratios and days to maturity of seven cultivars of *Brassica oleracea* var. *capitata* L. at three, five and seven weeks from germination.

Cultivar	Days to Maturity
1. Golden Cross	78
2. Ventura	82
3. Jet Pak	85
4. Earlimart	92
5. Early Vienna	98
6. Red Head	106
7. Storage Green	130

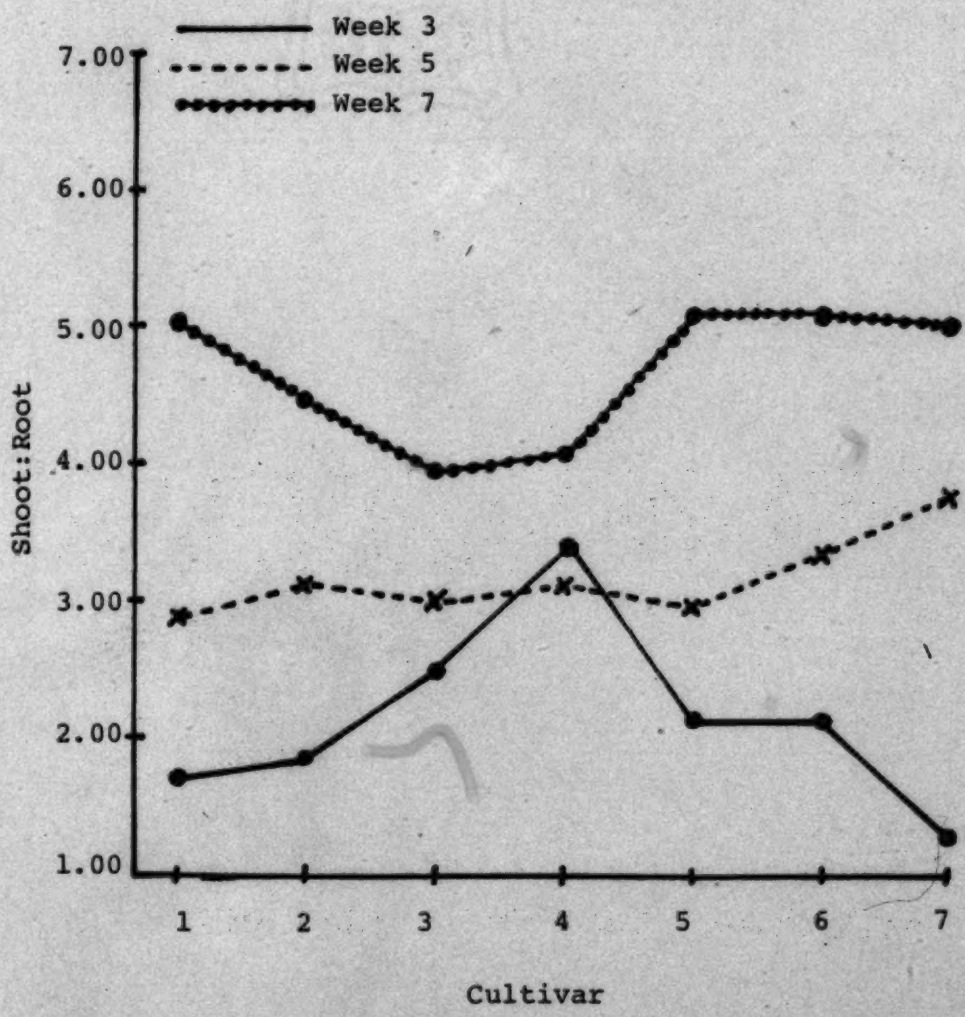


Table 31. Days to maturity and average shoot:root ratios of four replications of seven cultivars of *Beta vulgaris* at three, five, and seven weeks from germination.

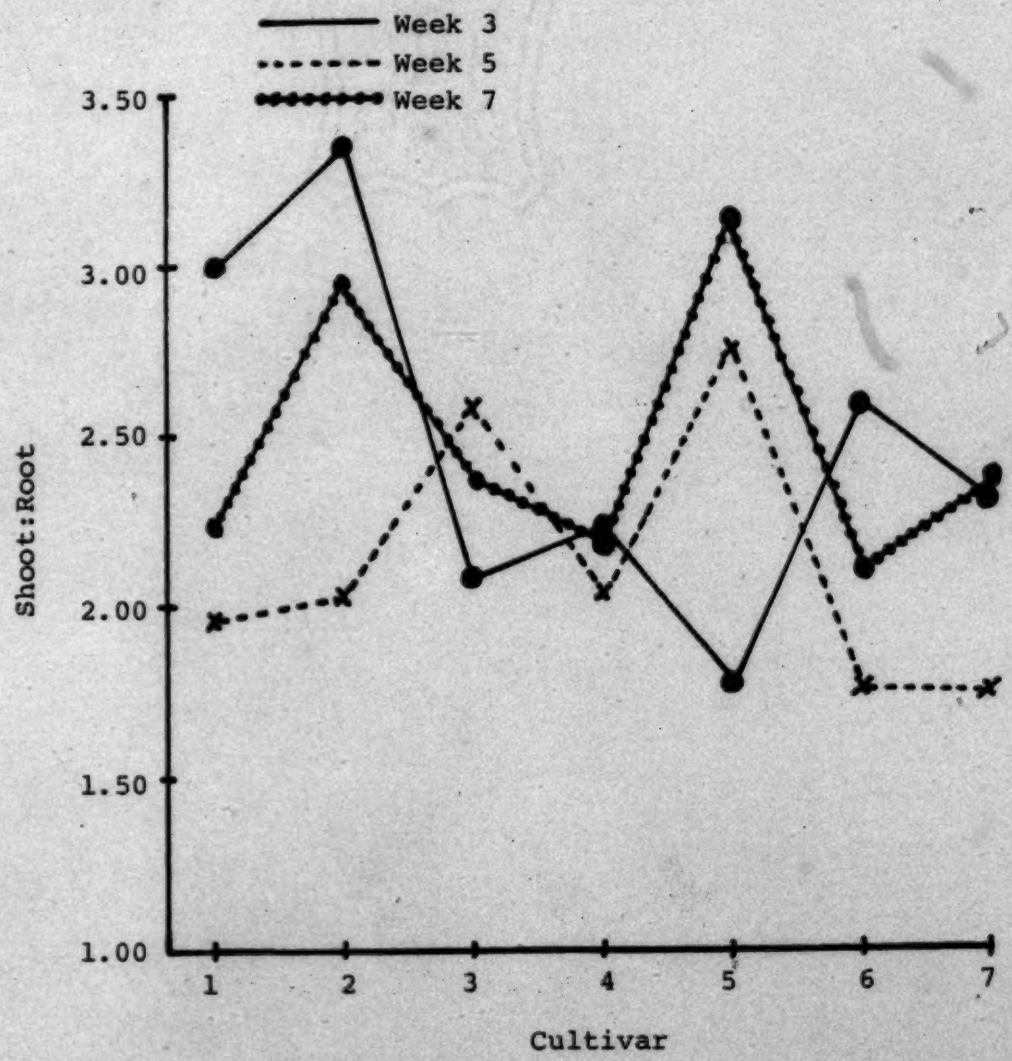
Cultivar	Days to Maturity	Shoot:Root Week 3	Week 5 *	Week 7
Mono Germ	45	3.0339	1.8917 c	2.2372
Burpee's Golden	50	3.3660	2.0252 b c	2.9230
Early Wonder	55	2.1018	2.5971 a b	2.3733
Cylindra (Formanova)	58	2.2194	2.0407 b c	2.1710
Detroit Dark Red	60	1.7900	2.7519 a	3.0728
Green Top Bunching	65	2.6142	1.7829 c	2.0872
Winter Keeper	78	2.3295	1.7760 c	2.3576
Correlation between days to maturity and shoot:root ratio		N.S	-0.16	N.S

* Numbers in this column not followed by the same letter are significantly different from each other at the 5% level as judged by Duncan's new multiple range test.

Other columns show no significant difference.

Figure 11. Average shoot:root ratios and days to maturity of seven cultivars of *Beta vulgaris* at three, five and seven weeks from germination.

Cultivar	Days to Maturity
1. Mono Germ	45
2. Burpee's Golden	50
3. Early Wonder	55
4. Cylindra (Formanova)	58
5. Detroit Dark Red	60
6. Green Top Bunching	65
7. Winter Keeper	78



C) Discussion and Conclusions

Significant differences were found between shoot:root ratios and days to maturity at certain stages.

Tomato showed a significant difference only at week seven and only cultivar two, Early Girl, was different from the other cultivars. The data indicates a weak negative correlation between shoot:root ratios and days to maturity. Since there was no significant difference at weeks three or five then possibly the difference of the particular replications of cultivar Early Girl is not representative of the whole population. It appears that the differences within cultivars are greater than differences among cultivars.

Cabbage showed a similar trend. No significant difference at weeks three and five and only two of the seven cultivars differed at week seven. There was no significant correlation, and as with tomato the differences within a cultivar are greater than among cultivars.

Beet again shows the same trend.

This differs from Badani's (1974) conclusion of a positive correlation between shoot:root ratios and days to maturity. He stated that no replications were made so therefore he could not detect variability within a cultivar.

Figure 8, page 92, indicates a relationship between nitrogen, phosphorus and days to maturity. In early cultivars phosphorus is high and nitrogen is low. If these were the only factors involved then there would be a small shoot:root ratio.

Conversely late cultivars would have high shoot:root ratios because nitrogen is high and phosphorus is low. However, the situation is more involved.

In early cultivars with low nitrogen shoot growth is restricted. Since the shoots produce carbohydrates which are used for growth, the small shoot in early cultivars would result in a limitation of root growth due to low carbohydrate levels.

In late cultivars where nitrogen is high and phosphorus is low, shoot growth is again restricted because low phosphorus levels delay development and reduce growth of the entire plant. With shoot growth limited, carbohydrate production would be reduced. With less carbohydrates available, less would be transported to the root, limiting its growth.

In the midseason cultivars where both nitrogen and phosphorus are in adequate quantities, overall plant growth is greater. With more shoot producing more carbohydrates, more carbohydrates are exported to the root, allowing the root to grow even more. If no other factors are involved then although the overall plant would change in size between early and late, the proportion of root to shoot may not change.

This work suggests that shoot:root ratios do not differ significantly between early and late cultivars.

Some problem was found in retrieving all the root

system. If this experiment was to be repeated, the plants should be grown hydroponically with the only media being one to which roots cannot fasten. Loss of roots during harvest contributed to the variability among cultivars. Additional replications may be of value in clarifying differences among cultivars.

SUMMARY AND CONCLUSION

Plants are a complex of interrelated systems which make it very difficult to isolate one system and prove that it correlates with days to maturity. The five possible indicators of early maturity have been shown to have little predictive value. However, they do give some increased understanding of the physiology associated with earliness.

Further experiments with peroxidase should be discontinued as it has been strongly shown that no relationship exists with early maturity. Future experiments should consider effects of air and soil temperatures. Acclimation to environmental parameters is an aspect of earliness that should be examined in future studies of respiration and net assimilation.

The selection of cultivars should also be reviewed. The relative earliness of the cultivars should be determined during each experiment as growing conditions may cause the days to maturity to vary from the days determined by others.

Future experiments should not attempt to find indicators of predictive value but should concentrate on increasing the understanding of earliness which may prove useful in influencing plant growth in the future.

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APPENDIX ONE

Peroxidase Determination Solutions

I. Hydrogen peroxide (3×10^{-3}M):

Stock solution: dilute 0.66 ml hydrogen peroxide (BDH Chemicals, Toronto, analytical grade, not less than 85.0%) (30% W/V) to 200 ml with doubly distilled water. Adjust the solution to exactly 0.03M (e.g. titrate against 0.1N $KMnO_4$ (Merck and Co. Inc., Rahway, New Jersey, analytical grade 100%); 10 ml 0.03M $H_2O_2 \Leftrightarrow$ 6 ml 0.1N $KMnO_4$). Just before use dilute stock solution 1:10 with doubly distilled water.

II. p-Phenylenediamine (1% W/V):

Dissolve 1 g para-phenylenediamine, $C_6H_4(NH_2)_2$, (Fisher Scientific Company, Fairlawn, New Jersey, certified grade 100%) in about 60 ml hot doubly distilled water, filter and wash the filter with about 25 ml hot doubly distilled water. Cool filtrate quickly and dilute to 100 ml with doubly distilled water.

III. Phosphate buffer (0.067M; pH7):

Dissolve 3.522 g KH_2PO_4 (J.T. Baker Chemical Co., Phillipsburg, New Jersey, analytical grade 100%) and 7.268 g $NaHPO_4 \cdot 2H_2O$ (Fisher Scientific Co., Fairlawn,

New Jersey, certified grade 99.9%) in doubly distilled water and make up to 1000 ml.

(from Luck, 1963)

APPENDIX TWO

Data For Respiration Experiments

I. *Lycopersicon esculentum*

Cultivar	mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$					
Week Four	Rep. 1	9 a.m. Adjust.	Rep. 2	9 a.m. Adjust.	Rep. 3	9 a.m. Adjust.
Rocket (9 a.m.)	19.6	19.6	20.0	20.0	19.7	19.7
Early Girl	20.9	20.9	19.0	19.0	19.2	19.2
Itabec	20.4	20.4	20.6	20.6	20.5	20.5
Rocket (noon)	10.9	(19.6)	10.5	(20.0)	10.6	(19.7)
Ultra Girl	10.9	19.6	11.7	22.3	11.2	20.8
VFN 8	10.8	19.4	11.2	21.3	11.2	20.8
Rocket (3 p.m.)	22.6	(19.6)	20.4	(20.0)	19.6	(19.7)
Amex VFN	19.9	17.3	21.8	21.4	20.6	20.7
Redstone	23.6	20.5	21.0	20.6	21.2	21.3
Week Five						
Rocket (9 a.m.)	19.2	19.2	33.0	33.0	20.6	20.6
Early Girl	25.8	25.8	22.9	22.9	16.4	16.4
Itabec	24.6	24.6	22.3	22.3	23.5	23.5
Rocket (noon)	6.1	(19.2)	5.8	(33.0)	6.2	(20.6)
Ultra Girl	6.4	20.1	5.8	33.0	6.4	21.3
VFN 8	6.9	21.7	6.2	35.3	6.8	22.6
Rocket (3 p.m.)	13.8	(19.2)	15.3	(33.0)	14.3	(20.6)
Amex VFN	13.5	18.8	14.4	31.1	13.2	19.0
Redstone	14.3	19.9	14.0	30.2	13.8	19.9
Week Six						
Rocket (9 a.m.)	8.8	8.8	9.7	9.7	9.1	9.1
Early Girl	8.1	8.1	8.3	8.3	8.4	8.4
Itabec	8.7	8.7	8.8	8.8	9.4	9.4
Rocket (noon)	6.5	(8.8)	6.1	(9.7)	7.0	(9.1)
Ultra Girl	6.2	8.4	6.6	10.5	6.5	8.4
VFN 8	6.8	9.2	6.2	9.9	6.5	8.4
Rocket (3 p.m.)	9.1	(8.8)	10.4	(9.7)	9.5	(9.1)
Amex VFN	9.7	9.4	10.5	9.8	9.9	9.5
Redstone	8.4	8.1	10.0	9.3	9.6	9.2

II. *Brassica oleracea*

Cultivar	mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$					
Week Four	Rep. 1	9 a.m. Adjust.	Rep. 2	9 a.m. Adjust.	Rep. 3	9 a.m. Adjust.
G. Cross (3 pm)	61.3	(99.9)	63.7	(108.2)	62.8	(98.2)
Ventura	57.2	93.2	49.6	84.2	53.3	83.3
Jet Pak	59.2	96.5	57.0	96.8	58.9	92.1
G. Cross (9 am)	99.9	99.9	108.2	108.2	98.2	98.2
Earlimart	105.8	105.8	100.3	100.3	103.9	103.9
Early Vienna	101.2	101.2	93.4	93.4	106.8	106.8
G. Cross (noon)	97.8	(99.9)	96.4	(108.2)	93.5	(98.2)
Red Head	103.7	105.9	91.0	102.1	94.3	99.0
Storage Green	102.5	104.7	101.5	113.9	97.2	102.1
Week Five						
G. Cross (9 am)	148.1	148.1	156.4	156.4	166.3	166.3
Ventura	144.2	144.2	154.2	154.2	148.9	148.9
Jet Pak	171.6	171.6	153.8	153.8	142.3	142.3
G. Cross (noon)	75.2	(148.1)	74.6	(156.4)	77.8	(166.3)
Earlimart	78.7	155.0	78.3	164.2	83.5	178.5
Early Vienna	87.4	172.1	78.3	164.2	82.5	176.3
G. Cross (3 pm)	51.7	(148.1)	48.6	(156.4)	51.2	(166.3)
Red Head	48.1	137.8	53.7	172.8	54.0	175.4
Storage Green	52.0	149.0	52.4	168.6	50.5	164.0
Week Six						
G. Cross (9 am)	186.8	186.8	176.3	176.3	169.4	169.4
Ventura	174.7	174.7	170.3	170.3	165.9	165.9
Jet Pak	167.3	167.3	172.8	172.8	162.9	162.9
G. Cross (noon)	54.7	(186.8)	57.8	(167.3)	59.5	(169.4)
Earlimart	56.6	193.3	58.7	170.2	63.8	181.6
Early Vienna	57.2	195.3	60.4	174.8	53.0	150.9
G. Cross (3 pm)	66.4	(186.8)	66.0	(167.3)	64.7	(169.4)
Red Head	65.7	184.8	69.0	174.9	71.5	187.2
Storage Green	74.3	209.0	62.8	159.2	66.5	174.1

III. *Beta vulgaris*

Cultivar	mg O_2 uptake·gram dry wt^{-1}·$hour^{-1}$					
Week Four	Rep. 1	9 a.m. Adjust.	Rep. 2	9 a.m. Adjust.	Rep. 3	9 a.m. Adjust.
Monogerm (9 a.m.)	37.0	37.0	31.7	31.7	30.7	30.7
Golden	31.2	31.2	32.4	32.4	35.5	35.5
Early Wonder	33.4	33.4	33.0	33.0	34.6	34.6
Monogerm (noon)	25.0	(37.0)	23.5	(31.7)	23.8	(30.7)
Cylindra	21.8	32.3	23.3	43.6	23.3	30.1
Detroit Dark Red	21.6	31.5	23.1	31.2	24.0	31.0
Monogerm (3 p.m.)	22.2	(37.0)	20.0	(31.7)	20.3	(30.7)
Green Top Bunch.	19.7	32.8	18.4	29.2	18.7	28.3
Winter Keeper	20.7	34.5	19.9	31.5	19.2	29.0
Week Five						
Monogerm (9 a.m.)	114.2	114.2	122.5	122.5	121.6	121.6
Golden	120.8	120.8	123.9	123.9	121.6	121.6
Early Wonder	116.5	116.5	118.6	118.6	117.2	117.2
Monogerm (noon)	21.7	(114.2)	21.3	(122.5)	20.8	(121.6)
Cylindra	20.9	110.1	22.0	126.5	21.6	126.3
Detroit Dark Red	20.1	105.8	20.7	119.0	19.9	116.3
Monogerm (3 p.m.)	26.1	(114.2)	24.9	(122.5)	24.3	(121.6)
Green Top Bunch.	24.6	107.6	27.3	134.3	23.4	117.1
Winter Keeper	24.6	107.6	22.6	111.2	22.9	114.6
Week Six						
Monogerm (3 p.m.)	13.0	(30.9)	11.3	(30.5)	13.5	(28.4)
Golden	11.8	28.0	12.1	32.7	11.7	24.6
Early Wonder	13.0	30.9	12.3	32.9	11.2	23.6
Monogerm (9 a.m.)	30.9	30.9	30.5	30.5	28.4	28.4
Cylindra	28.8	28.9	29.6	29.6	30.7	30.7
Detroit Dark Red	29.9	29.9	32.2	32.2	31.3	31.3
Monogerm (noon)	8.6	(30.9)	9.0	(30.5)	9.0	(28.4)
Green Top Bunch.	9.2	33.1	10.0	33.9	8.7	27.4
Winter Keeper	9.4	33.8	8.8	29.8	9.0	28.4

APPENDIX THREE

Data For Net Assimilation Experiment

I. *Lycopersicon esculentum*

Cultivar	mg $CO_2 \cdot gram^{-1} \cdot hour^{-1}$					
	0.73 $cal \cdot cm^{-2} \cdot min^{-1}$			0.182 $cal \cdot cm^{-2} \cdot min^{-1}$		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Rocket	-	-	-	2.31	5.01	1.85
Early Girl	2.41	3.71	3.98	-	-	-
Itabec	3.83	2.65	2.70	-	-	-
Ultra Girl	4.66	3.24	2.48	3.87	1.49	1.35
VFN 8	3.36	3.26	3.75	3.27	2.49	2.76
XP 271	3.09	4.38	0.91	-	-	-
Redstone	2.82	2.42	2.83	3.06	3.41	2.06

Cultivar	mg $CO_2 \cdot dm^{-2} \cdot hour^{-1}$					
	0.73 $cal \cdot cm^{-2} \cdot min^{-1}$			0.182 $cal \cdot cm^{-2} \cdot min^{-1}$		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Rocket	-	-	-	1.41	1.95	1.35
Early Girl	1.50	1.57	1.90	-	-	-
Itabec	2.04	1.68	1.48	-	-	-
Ultra Girl	2.28	1.62	1.33	1.89	0.82	0.68
VFN 8	2.45	2.06	3.10	2.39	1.56	1.89
XP 271	2.17	2.23	0.60	-	-	-
Redstone	1.69	1.53	1.53	1.84	1.85	1.30

II. *Brassica oleracea*

Cultivar	0.064 cal·cm^{-2}·min^{-1}					
	mg CO_2·gram^{-1}·hour^{-1}			mg CO_2·dm^{-2}·hour^{-1}		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Golden Cross	3.55	2.76	4.41	2.85	2.44	3.41
Jet Pak	2.77	3.81	4.58	2.38	2.92	3.62
Storage Green	5.41	3.78	3.40	4.08	2.57	2.58

III. *Beta vulgaris*

Cultivar	mg CO_2·gram^{-1}·hour^{-1}					
	0.023 cal·cm^{-2}·min^{-1}			0.064 cal·cm^{-2}·min^{-1}		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Mono Germ	2.86	0.48	0.65	6.71	13.51	6.18
Detroit Dark Red	1.35	0.67	2.83	8.76	8.28	11.30
Winter Keeper	1.99	3.08	6.81	5.21	9.05	11.46

Cultivar	mg CO_2·dm^{-2}·hour^{-1}					
	0.023 cal·cm^{-2}·min^{-1}			0.064 cal·cm^{-2}·min^{-1}		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Mono Germ	1.56	0.29	0.45	3.65	8.03	4.26
Detroit Dark Red	0.63	0.35	1.51	4.04	4.39	6.04
Winter Keeper	1.31	2.08	4.52	3.41	6.11	7.61

APPENDIX FOUR

Data For Leaf Area

I. *Lycopersicon esculentum*

Cultivar	Leaf Area (cm^2)				
Week Three	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Rocket	8.28	7.25	13.41	8.43	8.31
Early Girl	9.74	13.39	16.87	19.79	13.84
Itabec	7.98	9.12	10.45	15.47	11.39
Ultra Girl	18.98	13.15	9.44	29.09	18.86
VFN 8	15.13	13.55	19.25	15.77	13.18
XP 271	12.42	13.54	14.52	14.24	12.44
Redstone	9.67	9.90	8.57	2.74	11.91

Cultivar	Leaf Area (cm^2)				
Week Seven	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Rocket	713.90	392.92	416.45	375.25	528.65
Early Girl	687.17	599.19	806.56	595.37	500.88
Itabec	370.69	630.46	582.07	519.52	403.58
Ultra Girl	865.70	1009.66	1120.64	767.85	736.00
VFN 8	717.37	599.11	617.65	636.80	458.10
XP 271	379.78	379.40	429.33	512.26	487.19
Redstone	547.19	381.46	533.09	428.71	506.14

II. *Brassica oleracea*

Cultivar	Leaf Area (cm^2)				
Week Three	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Golden Cross	11.47	12.50	13.49	13.62	11.17
Ventura	16.64	17.90	18.57	20.25	14.27
Jet Pak	16.67	15.93	14.12	16.67	23.26
Earlimart	18.76	20.76	19.08	16.87	17.87
Early Vienna	7.62	9.76	13.59	9.12	14.82
Red Head	10.69	10.30	11.54	10.49	11.48
Storage Green	11.82	12.98	10.32	14.09	10.52

Cultivar	Leaf Area (cm^2)				
Week Four	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Golden Cross	64.83	97.20	87.99	84.58	89.90
Ventura	103.04	97.26	82.35	144.15	83.97
Jet Pak	104.46	79.46	94.13	99.10	160.74
Earlimart	144.97	145.79	140.47	144.11	164.72
Early Vienna	58.45	64.73	104.49	60.44	99.39
Red Head	62.61	62.43	43.54	67.33	74.07
Storage Green	88.10	71.66	79.75	97.15	89.54

Cultivar	Leaf Area (cm^2)				
Week Five	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Golden Cross	549.46	672.80	478.34	422.68	420.79
Ventura	576.98	532.43	619.41	549.96	539.70
Jet Pak	634.62	453.35	406.64	599.27	781.04
Earlimart	764.36	771.02	808.36	732.50	820.17
Early Vienna	313.90	462.83	566.27	451.95	657.18
Red Head	448.60	405.62	344.00	612.38	490.19
Storage Green	573.90	444.48	573.40	786.49	541.94

III. *Beta vulgaris*

Cultivar	Leaf Area (cm^2)				
Week Three	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Mono Germ	5.45	5.74	4.55	6.44	4.91
Golden	3.36	3.56	3.11	3.68	4.21
Early Wonder	7.88	4.54	7.77	4.57	6.32
Cylindra	4.90	8.33	7.67	5.79	7.60
Detroit Dark Red	6.92	6.81	6.82	6.31	6.79
Green Top Bunching	4.92	4.09	4.82	9.77	5.99
Winter Keeper	6.22	5.48	3.90	4.49	15.87

Cultivar	Leaf Area (cm^2)				
Week Four	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Mono Germ	72.58	64.78	139.27	183.71	98.56
Golden	71.57	103.45	41.71	65.62	61.51
Early Wonder	194.43	97.49	116.63	129.78	76.57
Cylindra	50.52	136.76	153.47	62.53	132.70
Detroit Dark Red	92.95	129.02	196.68	97.23	89.11
Green Top Bunching	50.59	69.52	70.14	116.85	55.03
Winter Keeper	83.56	131.06	67.28	67.94	138.64

Cultivar	Leaf Area (cm^2)				
Week Five	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Mono Germ	218.18	252.20	160.87	468.42	344.57
Golden	77.04	112.42	95.27	249.37	194.55
Early Wonder	249.62	236.17	245.00	182.74	279.66
Cylindra	259.17	209.55	273.86	247.44	289.49
Detroit Dark Red	290.44	291.12	323.14	350.71	410.03
Green Top Bunching	171.24	208.18	159.58	467.25	229.48
Winter Keeper	305.37	280.70	340.26	298.30	426.98

APPENDIX FIVE

Data For Shoot:Root Ratios

I. *Lycopersicon esculentum*

Cultivar	Shoot:Root Ratios			
Week Three	Rep. 1	Rep. 2	Rep. 3	Rep. 4
Rocket	1.2515	1.7216	5.0450	1.5484
Early Girl	1.0551	2.6667	5.3334	2.4907
Itabec	3.0721	2.7147	4.0708	3.4280
Ultra Girl	3.7650	1.7012	2.1887	2.2222
VFN 8	3.9892	2.4150	6.8077	2.0745
XP 271	3.3136	3.9212	2.6917	2.4660
Redstone	2.3342	2.7081	2.6599	1.8151

Cultivar	Shoot:Root Ratios			
Week Five	Rep. 1	Rep. 2	Rep. 3	Rep. 4
Rocket	3.8981	3.2094	2.2361	2.8358
Early Girl	2.8175	3.0990	3.5994	2.7674
Itabec	3.0977	2.6129	3.9990	3.8026
Ultra Girl	3.2687	3.0632	3.8821	3.0279
VFN 8	2.7334	1.5383	3.5334	3.3492
XP 271	3.5451	4.1321	3.7295	2.6372
Redstone	2.9615	1.7198	2.5380	1.9584

Cultivar	Shoot:Root Ratios				
Week Seven	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Rocket	3.5718	3.8852	5.1731	3.9942	4.0036
Early Girl	5.0416	4.3489	5.5641	6.8604	3.2711
Itabec	5.5843	4.5631	2.3069	4.8784	3.7418
Ultra Girl	3.6507	4.8878	4.2948	4.2815	2.9747
VFN 8	2.9442	2.4493	3.3620	3.4725	6.3674
XP 271	3.9085	4.8838	3.5074	3.5532	4.6764
Redstone	3.0160	3.7495	2.2651	3.7625	3.8328

II. *Brassica oleracea*

Cultivar	Shoot:Root Ratios			
Week Three	Rep. 1	Rep. 2	Rep. 3	Rep. 4
Golden Cross	1.5183	2.4894	1.6908	1.0577
Ventura	2.0235	2.9847	1.6864	0.6377
Jet Pak	2.5922	3.4828	2.8056	1.3500
Earlimart	3.1948	3.4276	4.3182	2.5107
Early Vienna	2.9272	3.1209	1.9330	0.6634
Red Head	1.6618	2.5472	2.0741	2.1234
Storage Green	1.0960	1.2358	1.0676	1.7462

Cultivar	Shoot:Root Ratios			
Week Five	Rep. 1	Rep. 2	Rep. 3	Rep. 4
Golden Cross	2.6350	2.6587	2.9383	3.2156
Ventura	3.9265	3.0085	3.4376	2.1434
Jet Pak	3.1924	2.2866	3.6101	2.9197
Earlimart	2.6411	2.3163	2.8985	4.3631
Early Vienna	2.9149	2.9906	2.8153	2.5003
Red Head	4.0126	2.9215	4.6560	2.0389
Storage Green	4.4809	2.7814	3.2662	4.2657

Cultivar	Shoot:Root Ratios			
Week Five	Rep. 1	Rep. 2	Rep. 3	Rep. 4
Golden Cross	5.2706	4.4856	5.0618	5.4258
Ventura	3.8216	4.3389	4.8906	4.6246
Jet Pak	5.3955	3.6004	3.5044	3.0530
Earlimart	3.6463	4.1484	4.1661	4.4119
Early Vienna	5.4961	3.8160	6.5131	4.9146
Red Head	4.3809	5.0446	5.3685	5.9411
Storage Green	4.9167	4.7742	5.2457	4.3550

III. *Beta vulgaris*

Cultivar	Shoot:Root Ratios			
Week Three	Rep. 1	Rep. 2	Rep. 3	Rep. 4
Monogerm	2.1144	2.2338	3.5137	4.2736
Golden	5.2500	1.5679	4.9794	1.6667
Early Wonder	3.1918	1.2500	2.5176	1.4478
Cylindra	1.8714	3.0303	1.1735	2.8025
Detroit Dark Red	3.5298	1.0732	1.3889	1.1682
Green Top Bunching	1.5450	2.3833	2.8765	3.6519
Winter Keeper	3.8382	3.1760	1.2037	1.1003

Cultivar	Shoot:Root Ratios			
Week Five	Rep. 1	Rep. 2	Rep. 3	Rep. 4
Monogerm	1.7491	1.5473	2.1540	2.1650
Golden	1.3595	2.2475	2.1962	2.2975
Early Wonder	2.6607	2.4623	2.4315	2.8341
Cylindra	2.7928	1.7159	2.0140	1.6402
Detroit Dark Red	2.1205	2.2147	2.7602	3.9123
Green Top Bunching	1.1238	1.8241	1.7418	2.4418
Winter Keeper	2.0642	1.3302	2.0308	1.6789

Cultivar	Shoot:Root Ratios			
Week Five	Rep. 1	Rep. 2	Rep. 3	Rep. 4
Monogerm	1.9006	3.5338	1.9858	1.5287
Golden	2.2249	2.5612	2.7292	4.1766
Early Wonder	1.0096	3.9639	1.6628	2.8570
Cylindra	2.5904	1.8127	2.1292	2.1518
Detroit Dark Red	3.6045	3.0536	2.6399	2.9933
Green Top Bunching	1.7407	2.8050	2.1169	1.6864
Winter Keeper	2.3272	3.3026	1.9722	1.8286